

BEST PRACTICE GUIDE FOR FOUNDRY SECTOR OF INDIA



For the BEE-GEF-World Bank Project

**FINANCING ENERGY EFFICIENCY
AT MSMEs**

A joint activity by:

**Bureau of Energy Efficiency (BEE)
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1.0 INTRODUCTION

The Institute for Industrial Productivity in partnership with WB-GEF-BEE program, initiated the project for development of a best practice manual for the foundry sector. MB Associates, foundry experts based in the UK was commissioned to provide industry specific technical guidance. The objective of the project was to develop an understanding of the overall performance of the Kolhapur Cluster, carry out a comparison of that performance and provide guidance as to the methods required for improvement. This is expected to enable the foundries to check and improve their efficiency and consumption of resources and energy.

As a part of the assignment, MB Associates, assisted by Shivaji University, carried out energy audit of few representative units identified by Kolhapur Engineering Association. Following the energy audits, a brief cluster study was carried out in an attempt to establish an overview of the size and make-up of the cluster as a whole.

Understanding the nature of the cluster allowed an extrapolation of the audit data which, together with the results of the cluster study, can show the energy consumption levels of the cluster. Such consumption levels can then be compared to similar groups of foundries in different parts of the world. Once consumption levels have been established for the cluster – and compared with other foundry groups – areas of potential improvement and the required actions were identified.

This report deals with Best Practices and Best Available Techniques for the key foundry operations. The objective of this section is to provide general information on state of the art equipment and procedures, specific information on comparing traditional equipment and procedures with best practice and recommendations on important items.

The width and depth of this section is tailored to address foundry men with a range of knowledge ranging from excellent knowledge about international standards of best practice foundry technology, to limited knowledge about best practice technology and procedures outside India.

The contents of this section can be considered to be in two parts:

- a discussion of the choice of alternative technologies available
- a description of the processes, materials and equipment necessary to realise the technology choice.

BEST PRACTICE TECHNOLOGY ALTERNATIVES

2.0 ALTERNATIVES FOR BEST TECHNOLOGY SELECTION

When selecting the appropriate technology for a competitive foundry it is not only to check the achievable physical performance levels (KPI), but especially the overall financial performance results. The most important factors to be considered are:

- the range of products to be produced
- the availability and quality of key resources such as raw materials, energy and labour
- the costs of key resources.

The best technology selection will aim for the overall optimum including product quality, process reliability and financial results.

2.1 Melting Technology

The best practice melting method can be established for each of the market sectors served by the foundry, as these are usually indicative of the volume and size/weight range of the castings required. A market sector chart (Exhibit A) for iron castings has been prepared as a guide to the selection options and best practice equipment for the major market sectors served by foundries. However, many foundries serve more than one market sector and the chart should only be used as a guide. It should enable foundries to build up a picture of their own “best practice” route.

For most cases the choice of melting facilities should be quite simple. There are, however, certain applications where the choice is more difficult and depends on specific parameters.

For high volume automotive production the melting plant could either be medium frequency induction furnaces or a long campaign cupola with a channel holding furnace. The choice between the two would depend on the following factors:

- number of alloy changes required
- the cost of electricity
- the cost of good quality coke.

For steel castings the choice is normally between induction furnaces and arc furnaces. A comparison of the relative advantages and disadvantages is given in Exhibit B.

The choice between arc furnace or coreless induction furnace normally depends on the volume of steel required for particular castings, which vary in size from less than a kilo to over 100 tonnes.

For the individual categories of foundries (as differentiated in Exhibit C) a matrix of Best Practice melting methods is given in Exhibit D. The index key for this matrix is given below:

- Long campaign cupola with channel holding furnace.
- Medium frequency induction furnaces.
- Cold blast cupola with oxygen enrichment.
- Arc furnace.
- Higher frequency induction furnaces.

2.2 Metal Treatment and Pouring

a) Iron Castings

To achieve close analytical and temperature control of iron it is necessary to have a heated receiver in front of a continuously melting furnace (eg cupola). Cold blast cupolas with intermittent tapping do not give consistent quality metal. The best method of holding high-volume grey iron is by an electric vertical channel induction furnace of sufficient capacity to even out fluctuations from the primary melter. The useful capacity of the channel furnace should be equivalent to two hours' melting rate.

Electric vertical channel furnaces are favoured in that:

- Hot inductor changes can take place without the need for the furnace to be cooled down. This can extend the working life to several years.
- Relining is quicker than on a horizontal channel furnace.
- They are more efficient than gas-fired receivers, as metal can be held between shifts and over weekends, allowing immediate start-up of production.

With medium frequency electric melting, a holding furnace will not be required if a later autopour or ladle capacity is sufficient to take a complete batch of metal.

Any further treatment of iron, to make SG or Compacted Graphite, should be carried out as late and as close to the mould as possible.

The most effective methods of producing ductile (SG) iron are by wire treatment or by the use of pure magnesium in a GF converter.

Distribution of the metal from the holding furnace to the moulding line can be carried out by automatic transfer of ladles or via a launder system to an automatic pouring unit. For alloying iron, direct material injection can take place when transferring the iron from the holding furnace to the pouring unit. On-line thermal analysis control, with automatic feedback to a wire injection system, is now possible.

Auto pour units are normally heated to maintain metal temperature, though for very high volume unheated units are used.

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If an autopour unit is to be used for pouring ductile iron, it should be of the unheated type. This is to prevent magnesium oxide from blocking the throat of the inductor.

The autopour unit should be “sealed” with metal poured using air or inert gas pressure. The autopour unit can be controlled by a timer or, better, by a laser monitoring the height of the metal in the pouring cup. The laser can be used to improve overall yield by avoiding an overflow at the end of the pour.

Inoculation can be carried out using stopper rod systems, which incorporate feeding of a wire inoculant through the stopper rod, or by using a weighed stream of fine ferro silicon. Blocks of inoculant can also be incorporated into the running system of the mould. Filters incorporated into the running system can control flow into the mould cavity, reducing turbulence and improving cleanliness.

Contact pouring has been developed when the mould is in direct contact with the pouring spout. This can reduce the size of the pouring cup and increase yield. Further developments have been the ability to identify automatically each mould, so that a defective casting (eg for run-out) can be scrapped automatically at punch-out without further processing.

For smaller foundries or those making large single grey or SG iron castings, best pouring practice will be to:

- use properly heated, covered ladles
- have minimum transfer of iron – each transfer is likely to cause a significant temperature drop
- adopt minimum pouring temperatures consistent with obtaining high quality castings, especially to limit fading of magnesium with SG iron.

b) Steel Castings

The type and extent of metal treatment or secondary steelmaking depends on the alloy being produced and the quality of the raw materials being melted. It is obviously not possible to describe the treatment of all types of alloys so a few examples are given below:

- carbon and low alloy steels
- corrosion resistant steels
- duplex stainless steels
- heat resistant steels
- high alloy steels, eg 17-4PH
- manganese steel.

➡ Carbon and Low Alloy Steels

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All of these alloys need to be deoxidised before pouring. This process can either be carried out in the furnace or in the ladle.

Furnace Deoxidation

Three groups of deoxidisers can be used as follows:

- Deoxidants which lower the oxygen content level relatively little in the first few minutes, i.e. during tapping, but which make improvements by lowering the oxygen when the steel is held before pouring. Among these are silicon and silicon-bearing commercial deoxidisers, such as silico-manganese and calcium-silicon.
- Deoxidants which directly after dissolving in the steel combine with most of the dissolved oxygen and separate from the liquid steel and are rapidly eliminated as primary oxides. A longer holding period is not successful in this case. Aluminium and titanium as well as aluminium-bearing deoxidisers such as ferro-aluminium and calcium-aluminium belong to this group.
- Deoxidants which, despite quick initial precipitation of part of the primary reaction products, and extensive lowering of equilibrium oxygen content, have high levels of deoxidation products, with such unsuitable physical properties that even with a long holding period, a still higher total oxygen or inclusion content remains. Zirconium is representative of this group.

Ladle Deoxidation

For simple requirements the final deoxidation of liquid steel for castings is mainly dependent on the use of aluminium.

For steels requiring special properties for special applications (eg high strength or high toughness or sub-zero temperatures), this improvement in cleanness and a lowering of sulphur content would lead to improved quality.

For these applications improved deoxidation can be obtained by using Ca-Si-Mn. Where further desulphurisation is then required then Ca-Si-Mg could be used.

Corrosion Resistant Steels

Typified by steel grade CN-7M.

Type CN-7M is a fully austenitic stainless steel, and is in a group of Fe-Ni-Cr-Mo alloys (sometimes with copper added) that contain more nickel than chromium. The steels were developed to improve upon the corrosion-resisting properties of 18/8 and 18/10/3 steels and are sometimes referred to as “super-corrosion-resisting” steels.

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This group of steels has exceptional resistance to crevice corrosion and pitting corrosion in sea water and brines and exhibits excellent resistance to caustic solutions, phosphoric acid (especially in the presence of halogens), sulphuric acid, sulphurous acid, sulphates and sulphites, nitric acid (strong, hot), hydrochloric acid (dilute) and hydrofluoric acid. The steels are suitable for use in the following industries: chemicals manufacture, food processing, metal cleaning and plating, oil wells and refining, paint and pigment, pharmaceutical, plastics, paper and pulp, soap and detergent, rubber and textiles, pump and valve.

Metal Treatment

On account of the high purity requirements of this steel, melting is usually carried out in the induction furnace. Careful selection of charge materials is essential; virgin components having extremely low residual elements should be used, eg pure nickel (pellet or cathode plate), pure copper, extra-low-carbon ferro-chrome (0.02% C max), ferro-silicon, ferro-manganese or manganese metal and molybdenum pellets or ferro-molybdenum. The purest iron that is economically feasible should be used.

Control of gas content is an essential part of melting procedure. Charge materials (including deoxidants) should be dried by pre-heating (at 500–600°C) and cleaned from any adhering contaminants. Patched linings or launders should be avoided and all refractories thoroughly dried. Melts of this type of steel should not follow ordinary commercial melts which may have contained relatively high levels of sulphur and phosphorus or other impurity elements. The use of CN-7M returns (runners, risers) in the charge is problematical; economics may dictate that small percentages are used, but ideally, since these are likely to contain high gas, segregated impurities, slag, scale and refractories, their use is best avoided.

Since the level of deoxidising elements (C, Si, Mn) is very low in these steels the level of oxygen in the melt will be high. An argon cover during melting and pouring (and argon flushing of the mould) can be advantageous, but does not necessarily guarantee completely defect free castings. Probably of greater importance is the minimising of oxygen contamination (clean, scale-free charges and additions), keeping a lid on the furnace, and a rapid melt-down and pour (which also minimises hydrogen and nitrogen pick-up).

AOD processing can also be recommended and when used, charges of lower purity may be employed. However, phosphorus (and other metallic impurities) are not removed by AOD and charge materials might still have to be very selective.

Deoxidation Practice

Because of the low Si, Mn and C levels in steels of this type, the oxygen levels will be high and deoxidation is necessary to control porosity. Aluminium has been used, but in CN-7M it has been found to produce thin films of alumina which (on machined surfaces) respond to dye penetrant examination and show up as fine cracks or “craze-cracking”. The use of the strong deoxidants aluminium, titanium and zirconium should be avoided and Ni-Ca or Ni-Mg used instead.

If the silicon content of the melt is very low the more common alloys can be used, namely Ca-Si, Ca-Si-Mn or Mg-Fe-Si. Alternatively degassing can be carried out in the ladle by vacuum degassing or VAD.

➡ Duplex Stainless Steels

Austenitic stainless steels can contain up to 20% ferrite, but the modern duplex steels contain 50% ferrite, or more. The presence of high amounts of ferrite considerably increases the strength, and also greatly improves the stress corrosion resistance although decreases the toughness at low temperatures. It also causes a marked refinement of the grain size of both the austenite and the ferrite (compared to fully austenitic and fully ferritic steels) and this can improve the resistance to inter-granular corrosion and increase the strength. The addition of nitrogen, which also raises strength, is a recent development.

In the present context, duplex stainless steels will be defined as those with ferrite contents between 35% and 65% and with chromium between 20% and 27%, nickel between 4% and 8%, molybdenum between 1.5% and 4% and the possible presence of copper and nitrogen.

Advantages of duplex steels over conventional austenitic stainless steels may be summarised as follows:

- proof strengths are higher and also high temperature strength
- resistance to uniform corrosion is higher
- resistance to crevice and pitting corrosion in chloride environments is higher
- resistance to sensitisation is higher, which also reflects in good weldability, obviating the need for stabilising elements.

Typical applications are:

- i) Pump and valve industry, for handling sea water, brines, brackish water, cooling water and desalination plant.
- ii) Chemical industry for use in sulphuric, acetic and phosphoric environments, resistance to abrasion in corrosive environments, desulphurisation scrubbers.
- iii) Sea water duties, eg ships, propellers, pumps, marine engineering.

- iv) Oil industry, resistance to sulphide stress corrosion cracking.
- v) Natural gas exploration, eg well head equipment, resistance to sour gas environments, transportation.
- vi) Off-shore technology, extraction and transportation of crude oil. Weight benefits can be achieved when duplex steels are used, compared to the use of conventional stainless steels.
- vii) Food industry.
- viii) Fertiliser industry.
- ix) Paper making industry, eg sulphite liquors, chlorides.
- x) Where higher hardness (compared to austenitic steels) is utilised to minimise erosion and galling.

Metal Treatment

Melting may be carried out in the arc furnace, although as is the case with all ELC grades, some difficulty might be experienced in blowing down to 0.03% C or less. Use high voltage to minimise carbon pick-up and raise electrodes when making additions. Make the nitrogen addition with low-carbon nitrogen-bearing ferro-chrome. The nitrogen content should be 0.10% to 0.14% in the solidified casting; above 0.15% there is a tendency to gas porosity.

In view of the difficulty in attaining low carbon contents in the arc furnace, in practice induction furnaces are often used. Impurities and residual trace elements should also be very low, i.e. sulphur (less than 0.004%), phosphorus, lead antimony and tin. The use of carefully selected raw materials is important.

The usual precautions hold when melting duplex steel in the induction furnace, viz, rapid meltdown of selected charge materials, rapid analysis and final additions, bring quickly to teeming temperature, minimise holding time. All charge materials, including lime, to be thoroughly dry; any refractory patching around slag line or spout to be thoroughly dried. Foundry returns in the charge should be limited to 70%. A cover of argon may be used during melting. Fully dried and pre-heated ladles should be ready for the teeming.

AOD refining is particularly suited to duplex steels, since low carbon and low sulphur contents can be readily attained and nitrogen content can be accurately adjusted. In general, much narrower alloying ranges are required for the duplex Cr-Ni steels than for the 18-8 conventional types and AOD refining is very helpful in this respect. If AOD plant is not available, AOD-melted stock may be purchased, although this is more suitable for charge material in the induction furnace.

Deoxidation Practice

Deoxidation for gas porosity control has to be carefully considered in relation to the precise melting technique used and the final analysis (eg nitrogen contents). Complex deoxidants based on calcium may be used and ordinary calcium alloys (viz Ca-Si and Ca-Si-Mn). Normally, the strong deoxidisers aluminium, titanium and zirconium are avoided, in view of the high nitrogen levels that prevail and the consequent danger of inter-granular fracture, reduced mechanical properties and corrosion resistance. It is better to rely on good steel melting practice to control oxygen and hydrogen contents. Vacuum ladle techniques should also be considered.

➡ Heat Resistant Steels

High alloy heat-resisting austenitic chromium-nickel steels are essentially of two types:

- those containing more than 17% Cr and more than 6% Ni, with the chromium content higher than the nickel content, and
- those containing more than 10% Cr and more than 23% Ni, with the nickel content greater than the chromium content.

For ease of identification, they will subsequently be referred to as Cr-Ni and Ni-Cr steels.

Both types of steel are used under oxidising conditions and are able to withstand greater loads and variation in temperature than the ferritic 28% Cr types. The Ni-Cr types can also be used under reducing conditions and can withstand severe changes in temperature and temperature gradients in parts that are not heated uniformly.

The steels are usually fully austenitic, and have high carbon contents in comparison to Cr-Ni corrosion resisting steels. Carbon is compatible in this respect, since like nickel it is an austenite stabiliser. However, it is the presence of carbon as carbides that imparts the required strength, especially at elevated temperatures when the carbides should not be dissolved.

With little specific requirements these alloys are normally melted and treated in arc furnaces. With regard to deoxidation, since the heat resisting Cr-Ni steels are usually made with quite high silicon contents, additional deoxidants are not normally required. In any case the use of aluminium should be avoided and if deoxidation is required then vacuum ladle techniques should be employed.

➡ High Alloy Steels

There are obviously several combinations of different high alloy steel but for an example the alloy type 17-4PH will be used as it finds use in several different applications.

17-4PH is the designation of a wrought steel developed by the Armco Steel Corporation. Its cast equivalent is designated CB-7Cu in ASTM specifications, but is most frequently

referred to generically as 17-4PH. It combines high strength at temperatures up to about 350°C with a corrosion resistance approximately between that of the 13% Cr and 18% Cr-8% Ni types of steel.

Since its strength is developed by precipitation hardening at relatively low temperatures, 17-4PH steel is suitable for parts which have to be machined. It finds use in the aerospace, chemical, food processing, marine, pulp and paper industries, and is used typically for impellers, gears, cams, pumps, valve parts (bodies, plugs, seats), propellers, fasteners. It is not immune to stress corrosion cracking in all conditions of processing and service application.

Metal Treatment

It is essential to melt and pour without delay in order to avoid excessive pick-up of nitrogen. For the same reason, the use of foundry returns should be severely limited. The nitrogen content of 0.05% should not be exceeded, otherwise erratic mechanical properties may be expected.

In view of the relatively low impact properties which characterise this type of steel, maintaining a low level of impurities will be beneficial.

Therefore ladle treatment by vacuum degassing or VAD may be appropriate.

Deoxidation Practice

In view of the relatively high level of nitrogen in steels of this type, aluminium should be used with caution, and preferably avoided altogether. Titanium has been used, but the resulting angular titanium nitrides or carbo-nitrides tend to lower impact properties. Calcium-silicon or Ca-Si-Mn can be effectively used, approximately 1% addition to the ladle, provided that the silicon manganese levels in the steel do not, as a result, exceed 0.7%.

Manganese Steels

Resistance to abrasion is not only a function of the steel, but also of the environmental conditions. Three types of abrasion are recognised:

- i) gouging abrasion, as when rocks or lump materials cut into a wearing surface, usually together with impact
- ii) grinding or high stress abrasion, as when two surfaces rub together in the presence of an abrasive material
- iii) scratching or low-stress abrasion, as when small loose particles move freely on the wearing surface.

13% Mn steel is universally applicable to conditions where gouging abrasion is predominant, or where gouging and grinding abrasion occur together. The steel has high strength and high toughness, and has the characteristic feature that as the surface is worn away, a freshly hardened surface is presented, provided that it is work hardened by gouging, pounding or impact. It is essentially non-magnetic and can be used for bumper plates in lifting electro-magnets, induction furnaces, etc.

13% Mn steel has excellent resistance in metal-to-metal wear, as in crane and mine-car wheels, sheaves, sprockets, pinions, gears, chains, track-pads, etc. Its most frequent use, however, is under dry abrasion conditions. It has very good resistance to gouging abrasion, intermediate to good resistance to grinding abrasion as in jaw-crushers and ball-mill liners, but relatively poor resistance to scratching abrasion. It, therefore, is widely used in mining, quarrying, oil-well drilling, steelmaking, cement-making, dredging, earth-moving, construction and track-work industries.

Metal Treatment

The steel can be melted in the arc or induction furnace, or refined in the arc furnace. There are three main methods:

- i) Melting using virgin materials, refused by normal refining, single or double slag practice in an arc furnace.
- ii) Melting foundry returns without refining, i.e. dead melting or semi-refining (arc or induction furnace).
- iii) Melting foundry returns with full refining, i.e. double slag in an arc furnace.

Method (ii) is more commonly used, there being a number of variations. Most straightforward is the melting of 100% foundry returns, which may be suitable for castings of very simple shape. Oxygen may be injected after meltdown in arc furnaces. A reducing slag is usually made up and any necessary alloying additions (FeSi, FeMn) made and the furnace tapped. For complex or crack sensitive castings, the weight of foundry returns in the charge is usually restricted to 40%, the remainder being bought-in carbon steel scrap and FeMn.

Induction furnace practice involves melting in a similar way, except the charges are usually mixed, i.e. 100% foundry returns are not used because of the build-up of gases they normally contain.

In the arc furnace, 100% foundry returns can be used, provided there is full oxygen refining, the melt fully killed (eg with Al) and a lime-based reducing slag kept fully deoxidised with powdered coal/coke and/or finely divided aluminium (turnings or shot). Fluorspar may be added if the slag becomes too viscous.

Methods (i) and (ii) are used mainly for heavy, complex shaped troublesome castings.

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Method (iii) allows good recovery of manganese but is costly in refractories because of the high temperature attained.

Phosphorus is a highly detrimental impurity, and is most easily kept to low levels by careful selection of charge materials. In the arc furnace it is possible to effect some removal, without too great a loss of manganese, by injecting powders during the refining stage. A mixture of $\text{CaO} + \text{CaF}_2 + \text{Mn}_2\text{O}_3$ in the ratio 5:3:2 has been found to be suitable.

Deoxidation Practice

Aluminium can be used for deoxidising 13% Mn steel. Because of the normally high nitrogen content of liquid 13% Mn steel, some foundries prefer not to use aluminium alone, but together with titanium. An alternative is to use Ca-Si-Mn without aluminium. All additions are made to the ladle.

2.3 Moulding Technology

It is considered that greensand systems will continue to be the main method of moulding for the production of iron castings and that chemically bonded systems will perform the equivalent operation when producing steel castings. As a guide, a market sector chart for the moulding of iron castings is given in Exhibit E.

The choice between different moulding methods depends on the following principal factors:

- the volume of castings required per annum
- the product types to be made
- the size (weight) of castings to be produced
- the product types to be made
- the dimensional tolerances that have to be maintained
- the surface finish that is required by the customer.

For the production of steel castings, one of the issues that may affect the choice of moulding system is the type and extent of the feeding system required.

It is best practice to use computer software for sizing feeder heads and casting simulation techniques for the design of pouring and running systems. The primary objectives are as follows:

- achieve specified quality standards
- maximise yield
- eliminate or minimise defects such as hot tearing, macro inclusions, shrinkages and gas porosity
- optimise surface finish quality

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- maintain steel cleanliness to avoid micro inclusions
- eliminate under riser segregation
- facilitate removal of excess metal by having minimum contact area of ingates and feeders with the casting, where possible on a flat surface.

Filters can be used to control metal flow rates into the casting. Filters can trap inclusions, which should be identified and prevented at source, rather than relying on filtration to always remove them.

For the individual categories of foundries (as differentiated in Exhibit C) a matrix of Best Practice moulding methods is given in Exhibit F. The index key for this matrix is given below:

- 1 Greensand high pressure moulding with flasks.
- 2 Greensand flaskless moulding.
- 3 Chemically bonded air-setting moulding.

2.4 COREMAKING

Every process and design choice made must be driven by the types of castings the foundry is making or plans to make in the future.

In order to select the core process for particular castings a number of questions need to be asked, for example:

- How many cores are needed?
- Should cores be made in sets to preclude gathering for assembly or should they be assembled into the mould at core setting?
- At what stage in the process are cores to be stored?
- Is sufficient core storage space provided?
- Where are core raw materials to be stored? Is sufficient space provided?
- Has sand reclamation equipment sufficient capacity and is the new core process compatible with existing moulding and core sand for reclamation?
- Have the latest equipment designs, such as automated core blowers that include core assembly within the cycle, been considered?
- How is core sand that is split removed from the machines?
- What environmental implications are there? Will additional dust collection, wet/dry scrubbers be needed? What environmental wastes or hazards will need to be disposed of?
- What process is being used currently and should the foundry change and introduce further complications to the process?
- What size of cores is required?

A core process suitability chart based on weight/size of cores is shown as a guide in Exhibit G using only the main core processes. The selection of a process may be determined, however, by technical reasons in that only certain processes are capable of meeting the required quality or volume.

It is useful to construct a process flow chart for existing core manufacturing facilities to see how any change or addition to these facilities, perhaps introducing a different core type, will affect the process flow.

An example of a typical process flow chart for an iron foundry using hot box and coldbox coremaking systems is shown in Exhibit H.

Generally speaking small or high volume cores would be produced by a coldbox core production method. As the size of the core increases or the number required decreases, then it becomes more likely that the core production method would change to an air setting system. There are obviously some notable exceptions to this generalisation.

The production of blocks and heads for automotive use would normally be completely automatic coremaking using the coldbox system. Core making “cells” would use robotic systems to make, check, assemble and paint the cores before sending them to the moulding line. In certain parts of the world the base sand quality does not allow certain difficult cores to be made satisfactorily in coldbox, eg water jacket cores. Under these circumstances the water jacket cores would be produced in shell or hot box.

Cores for ventilated discs are also produced on high volume coldbox automatic systems. For certain steel castings there are service requirements that need bolts or pins to fit the casting without the hole being machined. Such applications are mill liners and track pads. In these cases the cores would be produced in shell because of the surface finish requirements.

A matrix of core production methods for the categories of castings previously differentiated is given in Exhibit I. The index used is as follows:

- 1 Fully automatic robotic coldbox core production and assembly.
- 2 Fully automatic coldbox production.
- 3 Semi-automatic coldbox production.
- 4 Hot box or warm box cores.
- 5 Shell cores.
- 6 Air-set cores.

2.5 Casting Cooling and Separation

The method of separating castings from the moulding sand depends on the type of moulding method used, the type of casting being produced and the volumes involved.

Flasked greensand moulds would tend to be 'punched-out' followed by separation on a shake-out. Flask less moulds would tend to use a cooling and separation drum. Chemically bonded moulds tend to be separated using a shake-out, whereas very large or pit-moulds may be knocked-out manually.

For engine block production the method of separation needs also to separate the cores and from the moulding sand. This is done by having a two-stage shake-out system. Alternatively, the cope and drag boxes may be split and the casting 'dredged' out of the drag boxes using a manipulator. The casting and the cores are then knocked-out on a separate shake-out to the greensand.

The matrix for casting separation for the categories of castings previously differentiated is given in Exhibit J. The index used is as follows:

- 1 Two-stage shake-out or 'dredging' of castings.
- 2 Greensand shake-out.
- 3 Rotary cooling/shake-out drum.
- 4 Chemically bonded shake-out.
- 5 Manual separation.

Grey Iron castings, having once reached an acceptable temperature are normally cooled outside the mould. This can either be in a forced air cooling room, in normal atmosphere or in a cooling drum. The choice of cooling route depends on the size, complexity and volume of the castings being produced.

Blocks and heads could tend to be forced cooled, whilst smaller castings like brake discs, flywheels, etc, would be cooled in a rotating drum during separation.

For Ductile Irons casting cooling is a function of preventing the formation of primary carbides and providing the correct matrix composition (i.e. pearlite or ferritic).

There has been a growth in the market for castings such as 'as-cast ferritic SG Iron' which require longer cooling times in the mould prior to knock-out. When designing any new facility, the possibility of future expansion should be taken into account and space allowed for this.

Steel castings are normally allowed to cool within the mould until any chance of cracking or distortion has passed.

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Some steel castings made in greensand or chemically bonded sand are then normally shaken out in a conventional shake out and finally allowed to air cool, either in baskets or in storage bins. Higher volume production can use casting cooling conveyors for the final cooling of the castings.

Large steel castings are left to cool in situ, often in the casting pit. This can take several days or even weeks for the largest castings.

The use of solidification simulation packages will allow for optimum knock-out times to be determined.

The Best Practice Matrix for casting cooling is shown in Exhibit K. The index for this figure is as follows:

- 1 In mould plus forced draught cooling outside of mould.
- 2 In mould plus natural cooling using a cooling conveyor.
- 3 In mould cooling during production cycle.
- 4 Cooling in rotary drum.
- 5 In mould cooling to avoid internal stress plus natural air cooling.
- 6 In situ extended cooling.
- 7 In mould cooling then no further process cooling after knock-out.

Exhibit A: Market Sector Chart – Iron Foundries – Melting

Product Type/ Market Sector	Weight Range	Metal Type	Primary Melter			Holding Furnace	
			Long Campaign Cupola	Medium Frequency Induction	Cold Blast Cupola Oxygen Injection	Vertical Channel Induction (if needed)	Auto pour Furnace (if needed)
Automotive	up to 25 kg	GI	*			*	*
		SG		*		*	
	25–75 kg	GI	*	*		*	*
		SG		*		*	
	above 75 kg	GI		*	*	*	
		SG		*		*	
Pipe Fittings	up to 25 kg	SG		*		*	
	25-75 kg	SG		*		*	
	above 75 kg	SG		*		*	
Spun Pipe	0.08–1 m	SG	*			*	
General Engineering	up to 25 kg	GI	*			*	*
		SG		*			
	25-75 kg	GI	*	*		*	*
		SG		*		*	

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Product Type/ Market Sector	Weight Range	Metal Type	Primary Melter			Holding Furnace	
			Long Campaign Cupola	Medium Frequency Induction	Cold Blast Cupola Oxygen Injection	Vertical Channel Induction (if needed)	Auto pour Furnace (if needed)
	above 75 kg	GI		*	*	*	
		SG		*		*	
Building and Civil Engineering	up to 25 kg	GI	*			*	*
		SG		*		*	
	25-75 kg	GI	*	*	*	*	*
		SG		*		*	
	above 75 kg	GI		*	*	*	
		SG		*		*	
Machine Tools	up to 75 kg	GI			*		
	above 75 kg	GI			*		
Agricultural Machinery	up to 75 kg	GI		*	*	*	
		SG		*		*	
	above 75 kg	GI		*	*	*	
		SG		*		*	

Exhibit B Comparison of Arc Furnaces with Induction Furnaces for Steel Foundries

Arc	Induction
<ul style="list-style-type: none"> steel shell lined with refractory all water above the level of liquid metal lining wear measured by eye on small furnaces easy to repair longer lining campaign utilises heat of oxygen and metal reactions but counteracted by extracted air and combustion outside the furnace 480 kWh/tonne achievable in steel foundries melts most materials problems of carbon pick-up on 0.03% max grades noisy and difficult to quieten needs fume collection disposal problems with fume P can be lowered with slag practice, i.e. <0.010 N₂ 0.005–0.010% because of carbon boil 	<ul style="list-style-type: none"> water cooled copper tube lined with refractory – potential danger most have earth leakage to monitor lining wear difficult to repair hot easier to operate cheaper capital cost no oxygen injection practice 580 kWh/tonne is achievable melts most materials dependent on lining no risk of carbon pick-up from electrodes less noisy, easier to quieten less fume emitted fume not collected difficult to refine other than a carbon boil N₂ 0.010-0.012% and H₂ 3–4 ppm. Can pick up

<ul style="list-style-type: none"> • H_2 2–3 ppm because of carbon boil • able to handle slag-need slag making materials • slag to be disposed off • flexible • larger range of scrap size and quality • will tolerate sand, refractories, filters, etc • generally >5 tonne • 1 operative plus assistance at stages • melts 0.5–1.5 rated capacity • refractories cost reduced by use of water cooled linings low carbon stainless steels easier and quicker to produce • low carbon stainless steels easier and quicker to produce • can melt 100% returns 	<p>these elements from the atmosphere which is a disadvantage</p> <ul style="list-style-type: none"> • slag is less of a problem • size to a max of two-thirds furnace dia unless charged by hand • charge material should be clean, i.e. no sand or refractories • generally <3 tonne in steel foundries • 1 operative • melts 0.5–1.0 rated capacity • bag house dust can be re-melted • advantage of electro-magnetic stirring effect in homogenising composition • usually melt 50% returns max
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Exhibit C Product and manufacturing method classification

Grey iron product categories

Automatic moulding

GABH = automotive engine blocks and cylinder heads

GAAO = automotive other

GAAG = agriculture

GAMI = mining

Mechanised moulding

GMBH = medium sized engine blocks and heads (energy generation)

GMAG = agriculture

GMMI = mining

GMGE = general engineering

Manual (hand) moulding

GGBH = large size engine blocks and heads (energy generation)

GHMI = mining

GHGE = general engineering

Ductile iron product categories

Automatic moulding

DAAU = automotive other

DAGE = general engineering

Mechanised moulding

DMAU = automotive

DMGE = general engineering

Manual (hand) moulding

DHEN = energy generation components

DHCO = compressor components

DHGE = general engineering

Steel product categories

Automatic moulding

SARC = railway components (c)

SAMM = mining components (m)

SAAC = commercial vehicles (c)

SAGC = general engineering

Mechanised moulding

SMRC = railway components (c)

SMMM = mining components (m)

SMPC = pumps and valves (c)

SMPS = pumps and valves (s)

SMGC = general engineering (c)

SMAC = commercial vehicles (c)

Manual (hand) moulding

SHMM = mining components (c)

SHPC = pumps and valves (c)

SHEA = energy components (a)

SHGC = general engineering (c)

c = carbon steel, s = stainless steel

m = manganese steel, a = high alloy steel

Exhibit D Best Practice Guide – Melting Matrix

Foundry Product Categories	32 Categories	Grey an Alloy Irons	Ductile Iron and CGI	Steel
Automatic Moulding				
Blocks Heads	ABH	1 or 2		
Other Automotive	AAO/AAO	1 or 2	2	
Machine Agriculture	AAG	2		
Mining	AMI/AMM	2		4 or 5
General Engineering	AGE/AGC		2	4 or 5
Railway	ARC			4
Commercial Vehicles	AAC			4 or 5
Mechanised Moulding				
Blocks/Heads En.	MBH	2		
Agriculture	MAG	2		
Mining	MMI/MMM	2		4
Mechanised General Engineering	MGE/MGE/MGC	2	2	4
Automotive	MAO		2	
Railway	MRC			4
P&V(cs)	MPC			4
P&V(ss)	MPS			4 or 5
Commercial Vehicles	MAC			4
Hand Moulding				
Blocks/Heads En.	HBH	2 or 3		
Mining	HMI/HMM	2		
Hand General Engineering	HGE/HGE/HGC	2 or 3	2	4
Energy	HEN/HEA		2	4
Compressors	HCO		2	
P&V(cs)	HPC			4

Exhibit E Market Sector Chart – Iron Foundries – Moulding

Product Type/ Market Sector	Weight Range	Greensand		Chemically Bonded	Permanent Mould
		Flask less	Mould Flasks		
Automotive	up to 25 kg	*			
	25–75 kg	*	*		
	above 75 kg		*		
Pipe Fittings	up to 25 kg	*			
	25–75 kg	*	*		
	above 75 kg			*	
Spun Pipe	80 mm to 1 m				*
General Engineering	up to 25 kg	*			
	25–75 kg	*	*	*	
	above 75 kg		*	*	
Building and Civil Engineering	up to 25 kg	*			
	25–75 kg	*	*		
	above 75 kg		*	*	
Machine Tools	up to 25 kg		*		
	25–75 kg			*	
	above 75 kg			*	
Agricultural Machinery	up to 75 kg		*		
	above 75 kg		*	*	

Exhibit F Best Practice Guide – Moulding Matrix

Foundry Product Categories	32 Categories	Grey an Alloy Irons	Ductile Iron and CGI	Steel
Automatic Moulding				
Blocks Heads	ABH	1		
Other Automotive	AAO/AAO	1 or 2	1 or 2	
Machine Agriculture	AAG	1 or 2		
Mining	AMI/AMM	1 or 2		1 or 2
General Engineering	AGE/AGC		1 or 2	1
Railway	ARC			1
Commercial Vehicles	AAC			1
Mechanised Moulding				
Blocks/Heads En.	MBH	1		
Agriculture	MAG	3		
Mining	MMI/MMM	3		3
Mechanised General Engineering	MGE/MGE/MGC	1 or 3	1 or 3	3
Automotive	MAO		1 or 3	
Railway	MRC			1 or 3
P&V(cs)	MPC			3
P&V(ss)	MPS			3
Commercial Vehicles	MAC			3
Hand Moulding				
Blocks/Heads En.	HBH	3		
Mining	HMI/HMM	3		3
Hand General Engineering	HGE/HGE/HGC	3	3	3
Energy	HEN/HEA		3	3
Compressors	HCO		3	
P&V(cs)	HPC			3

Exhibit G Size Suitability Chart – Core making

Size of Core	Shell	Hot Box Warm Box	Cold Box	No-Bake
Very small cores (< 0.5 kg)	*	*	*	
Small cores (< 1 kg)	*	*	*	
Medium-sized cores (1-20 kg)	*	*	*	
Large cores (20-50 kg)		*	*	*
Very large cores (750 kg)				*

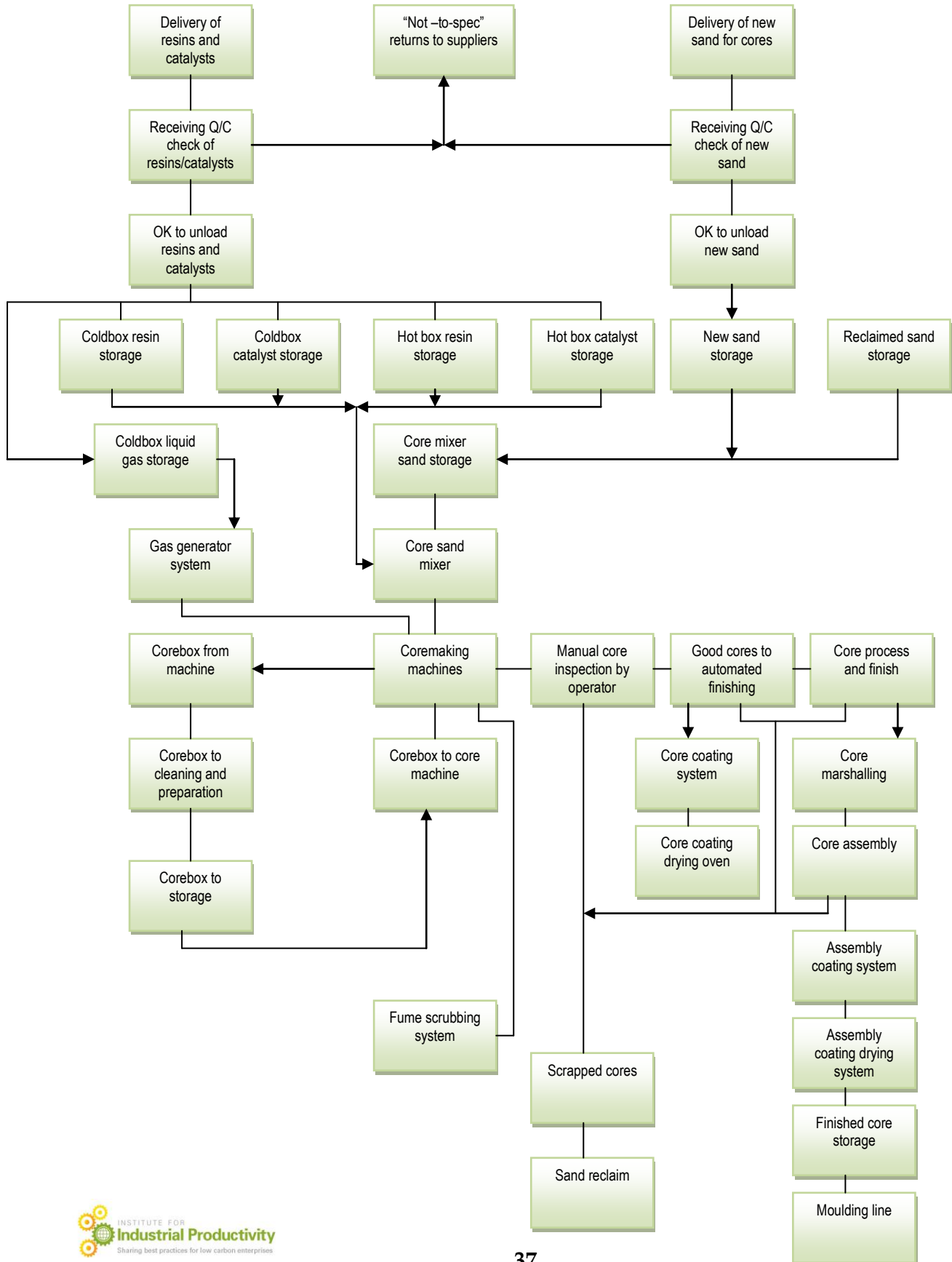
Exhibit H Typical Process Flow – Core making


Exhibit I Best Practice Guide – Core making Matrix

Foundry Product Categories	32 Categories	Grey an Alloy Irons	Ductile Iron and CGI	Steel
Automatic Moulding				
Blocks Heads	ABH	1 or 1&4 or 5		
Other Automotive	AAO/AAO	2	2 or 3	
Machine Agriculture	AAG	2 or 3		
Mining	AMI/AMM	5		5
General Engineering	AGE/AGC		2 or 3	2 or 3
Railway	ARC			2
Commercial Vehicles	AAC			2 or 3
Mechanised Moulding				
Blocks/Heads En.	MBH	2 or 2&4 or 5		
Agriculture	MAG	3 or 6		
Mining	MMI/MMM	5 or 6		5
Mechanised General Engineering	MGE/MGE/MGC	3 or 6	3 or 6	3 or 6
Automotive	MAO		2 or 3	
Railway	MRC			3
P&V(cs)	MPC			3 or 6
P&V(ss)	MPS			3 or 6
Commercial Vehicles	MAC			3 or 6
Hand Moulding				
Blocks/Heads En.	HBH	3 or 4 or 6		
Mining	HMI/HMM	5&6		5&6
Hand General Engineering	HGE/HGE/HGC	6	6	6
Energy	HEN/HEA		6	3 or 6
Compressors	HCO		6	
P&V(cs)	HPC			6

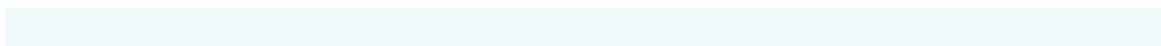
Exhibit J Best Practice Guide – Casting Separation Matrix

Foundry Product Categories	32 Categories	Grey an Alloy Irons	Ductile Iron and CGI	Steel
Automatic Moulding				
Blocks Heads	ABH	1		
Other Automotive	AAO/AAO	3	3	
Machine Agriculture	AAG	2		
Mining	AMI/AMM	2 or 3		2
General Engineering	AGE/AGC		2 or 3	2
Railway	ARC			2
Commercial Vehicles	AAC			2
Mechanised Moulding				
Blocks/Heads En.	MBH	2 or 4		
Agriculture	MAG	4		
Mining	MMI/MMM	4		4
Mechanised General Engineering	MGE/MGE/MGC	2 or 4	2 or 4	4
Automotive	MAO		2 or 4	
Railway	MRC			2 or 4
P&V(cs)	MPC			4
P&V(ss)	MPS			4
Commercial Vehicles	MAC			4
Hand Moulding				
Blocks/Heads En.	HBH	4		
Mining	HMI/HMM	4		4
Hand General Engineering	HGE/HGE/HGC	4 or 5	4 or 5	4 or 5
Energy	HEN/HEA		4 or 5	4 or 5
Compressors	HCO		4 or 5	
P&V(cs)	HPC			4

Exhibit K Best Practice Guide – Casting Cooling Matrix

Foundry Product Categories	32 Categories	Grey an Alloy Irons	Ductile Iron and CGI	Steel
Automatic Moulding				
Blocks Heads	ABH	1		
Other Automotive	AAO/AAO	4	3 or 4	
Machine Agriculture	AAG	2		
Mining	AMI/AMM	4 or 7		2
General Engineering	AGE/AGC		3 or 4	2
Railway	ARC			2
Commercial Vehicles	AAC			2
Mechanised Moulding				
Blocks/Heads En.	MBH	1 or 2		
Agriculture	MAG	2 or 7		
Mining	MMI/MMM	3 or 7		5
Mechanised General Engineering	MGE/MGE/MGC	3 or 7	3	5
Automotive	MAO		3	
Railway	MRC			5
P&V(cs)	MPC			5
P&V(ss)	MPS			5
Commercial Vehicles	MAC			5
Hand Moulding				
Blocks/Heads En.	HBH	5 or 6		
Mining	HMI/HMM	6 or 7		5 or 6
Hand General Engineering	HGE/HGE/HGC	5 or 6	3 or 6	5 or 6
Energy	HEN/HEA		3 or 6	5 or 6
Compressors	HCO		3 or 6	
P&V(cs)	HPC			5 or 6

BEST AVAILABLE TECHNOLOGY, PROCESSES AND EQUIPMENT



3.0 MELTING

3.1 Raw Materials

a) Controlling Raw Materials

Raw materials for the manufacture of castings must be selected and controlled to ensure that castings have the mechanical properties and chemical composition desired by the customer and are free from defects.

Amongst the various raw materials input into the foundry, metallic take the lion's share both in terms of technology and economics.

Metallic Raw Materials

- i) Steel scrap
- ii) Bought cast iron scrap
- iii) Pig iron
- iv) Return scrap

Ferro Alloys

Each of these materials should be purchased to:

- range of compositions
- range of quality
- range of physical form.

The selections and quantity requirements of these metallic will depend on the melting method and techniques, the types and grades of irons to be produced, the skill of the operators and possibly local factors such as scrap availability.

b) Ferrous Scrap

Steel scrap has quite deliberately been placed as the number one raw metallic.

Over the last decade technical advances in cupola techniques, electric furnace melting and metallurgical skills have resulted in an increase in the use of steel scrap in foundry melting operations.

The scrap industry has made considerable efforts to ensure that it supplies the qualities of scrap required by the foundry industry. Many scrap merchants have geared their business to local foundries. However, it is up to the individual foundry to:

- specify the quality and quantity requirement
- carry out the necessary visual check on every individual load of scrap – remember that visual inspection means checking before and after tipping
- visit the scrap merchant's yard on a regular basis to ensure continuity of quality and supply.

The scrap merchant's quality is only as good as his scrap source, plus his processing equipment. The former can change, especially when prime steel is at a premium, resulting in scrap of unknown qualities being introduced into the system.

Bought Cast Iron Scrap

Similar remarks concerning quality control apply to cast iron scrap as to steel scrap.

Categories and approximate ranges of composition for the main types of cast iron scrap are shown in Exhibit L.

The controlling element in bought cast iron scrap is considered to be phosphorus and even relatively medium phosphorus contents of 0.3% or less are detrimental to the production of the higher strength grey irons.

However, with certain specific exceptions, the phosphorus levels of cast iron scraps have reduced considerably over the last 20 to 30 years. In fact, the only commercial way to produce a high phosphorus iron is to add ferro phosphorus.

Control

As with steel scrap loads, a visual inspection of each individual load is essential, and again check before and after tipping, including the bottom of the transport vehicle.

Attention must be paid to possible sources of contamination such as:

gas works scrap	–	high sulphur
enamelled scrap	–	lead, boron and antimony
petrol engine scrap	–	lead, aluminium, etc, plus the possibility of small quantities of chromium

Cast Iron Swarf and Borings

The vast majority of cast iron borings originate from low phosphorus sources and as such are a useful, relatively low cost raw material for many iron foundries.

It can be briquetted, packed in canisters and used in cupola operations. Commercial success depends on the quality of briquette or canning operations as there can be serious losses in the melting operation.

The coreless induction furnace is an ideal melting unit providing the borings are dry and relatively free from rust and foreign matter.

Briquetted cast iron borings should be free from corroded lumps and excessive cutting fluids.

Pig Iron

Pig irons are produced by blast furnaces from iron ore and from ferrous scrap in cupolas or electric furnaces (refined pig irons), or as by-products from other processes such as vanadium or titanium oxide production. These latter pig irons are usually high purity irons most suitable for ductile iron production.

The composition of refined pig irons can be adjusted to comply with customer requirements, including a known residual content or added alloys with a specified range of alloy content.

Typical pig iron compositions, with the exception of high purity irons, are shown in Exhibit M.

Control

Pig iron is ordered to a given specification range and should be accompanied by a supplier's certificate of composition which should include the major residual contents.

No two batches are the same and unless the operation can withstand a reasonable tolerance in casting compositional range, each batch (which in the case of blast furnace irons may have variations in the batch) should be kept separate. This ideal may not be possible in large melting plants.

Foundries should insist on a certificate of analysis and also carry out analytical checks to ensure a quality material.

Pig iron is an expensive metallic and should be used as a general quality control in the metallic charge, i.e.:

- provide and even out carbon “pick-up” variations
- provide and even out silicon levels
- control phosphorus levels
- ensure a better mixing in cupola operations which have inadequate wells and fore hearth facilities
- as a control for excessive residual element levels and possible gas levels when high steel charges are used.

Return Scrap

The return scrap of each individual foundry should be of a known and generally consistent composition. It should be used to the maximum consistent with obtaining the desired composition of the castings to be manufactured.

Control

Each grade of scrap should be kept separate. Large pieces should be broken to a size suitable for individual furnace requirements.

c) Ferro-Alloys

Ferro alloys are used as additions to ensure control of elements such as silicon and manganese in the standard non or low alloy irons.

The high alloy irons such as Ni hard, Ni resist and high chromium iron, represent a small percentage of the iron foundry industry and require special attention to their choice of alloys and ferro alloys.

Ferro silicon	Most common grades in lump form contain 75–80% and 45–50% silicon levels.
Silicon carbide	In lump form containing 55–60% Si and 25–30% C
Ferro manganese	Usually obtained in lump form and contains 75–80% manganese.

It is often convenient to add small additions of silicon manganese and chromium in the form of briquettes in cupola operations.

Briquettes contain a fixed amount of alloy and avoid the necessity of weighing the addition. They are therefore very useful to the small and medium foundries that do not possess suitable, accurate weighing equipment.

The use of larger amounts of ferro silicon in cupolas can result in excessive silicon variations unless suitable mixing volumes are provided in wells, receivers or ladles.

Do not rely too much on the cupola for mixing purposes as it is very possible to obtain a wide variation in silicon content from the well, even with a tap and bott system.

Control

Ferro alloys should be checked that they comply with the foundry's specification for size, grading and composition.

In particular, ferro silicon should be checked for fines as this is a source of high silicon losses and hence variation in silicon content in melting operations.

Briquettes should be checked for consistency of weight and friability. Instability of briquette can also lead to high silicon losses in the cupola.

In both cases alloy content should be occasionally checked by the foundry or by an independent laboratory.

Accurate weighing of ferro alloy additions on suitable scales is an absolute essential to control silicon and manganese contents. When briquettes are used, ensure the chargers can count!

d) *Subsidiary Raw Materials*

These materials, which must be controlled, include:

- coke
- carburisers
- fluxes
- inoculants
- alloying additions

Coke

Coke is the primary energy source in cupola operations and coke quality is the key to carbon and sulphur pick-up. Carbon pick-up is of particular importance when high steel charges are used.

Chemical and physical properties should have the following characteristics:

moisture	–	4% max
ash	–	9% max
volatile matter	–	1.0% max
sulphur	–	0.9% max
50 mm shatter index	–	90% min
mean size	–	110 mm min
undersize	–	not more than 4% of pieces less than 50 mm

Serious coke breakages can occur through inefficient handling at all stages from the coke oven, to and in the foundry.

Each coke delivery should be checked visually for size to ensure that there has been no serious degradation.

Examination of the coke structure may give a clue to its behaviour in the cupola. A good close/dense grain structure normally denotes a good operating coke. Coke strength is related to its final size and weak friable coke will result in excessive breakage and fines.

Serious coke breakages can occur at the foundry, resulting in a high percentage of small coke below 50 mm in size.

Small cokes can reduce tapping temperatures and carbon pick-up and may require an increased coke percentage to maintain good cupola operation. Increasing coke percentage will reduce melting rates unless air volumes are increased.

Care should be taken if coke is stocked for any length of time as this will result in degradation, and possibly a reduction in carbon pick-up and tapping temperatures.

Control

Inspect each delivery for size and structure. Record the name of the supplier, haulier and time and delivery of each consignment.

Retain a sample from each delivery for chemical analysis. If laboratory facilities are available, check ash, sulphur and volatile matter. If laboratory facilities are not available and coke quality is suspect, arrange for an outside analysis.

If the load contains excessive small coke and fines, do not use unless absolutely necessary. Under these circumstances retain a proportion of the load for supplier's examination.

Do not store coke except on an emergency basis. Use the stored coke at regular intervals and replace with fresh supplies.

Carburisers

Carburisers are mainly used in electric furnaces to carburise high steel charges to the appropriate carbon level.

They are also used in external treatment processes such as porous plug ladles, and shaking ladles, again to raise carbons to required levels.

Carburising materials available in the UK are mainly based on the synthetic graphites, petroleum cokes and to a lesser degree metallurgical cokes.

Approximate analyses are given in Exhibit N.

Graphites

These materials are used for carburising base irons for ductile irons, malleable irons and also grey irons when it is desirable to restrict nitrogen pick-up, or when sulphur content is in excess of 0.05% and a high degree of nucleation is required.

Non graphites (petroleum or metallurgical cokes)

These materials are used for ductile and malleable iron production. In the case of ductile irons, petroleum and metallurgical cokes are only used when the metal is to be desulphurised.

They are used extensively in the production of grey irons for the following reasons:

- To obtain an increase in tensile strength due to increased nitrogen content
- Care must be taken that the increased nitrogen content does not give rise to nitrogen fissure defects in the finished casting.
- To avoid over-nucleation which could give rise to shrinkage defects.
- To increase sulphur contents of some irons to above 0.05% making them more responsive to inoculation.

Control

- Select the correct carburising material and grade for the application. When purchasing specify these two criteria.
- Grading is of prime importance and can affect solution rate, carburising potential and carbon losses. If the material is too fine, the carbon will float away on thermal air currents. If too coarse, low temperatures and low turbulence will result in slower carbon solution and low recovery.
- Check every consignment for specific type and grading, and store the material under cover.

- Segregate carburising agents if more than one type is used.
- Check carbon recoveries on a statistical basis to ensure quality continuity.

Fluxes

- Fluxes are added to the cupola to give a fluid slag with the impurities in the charge, sand, rust, ash, etc, plus refractory lining attacked and removed during the melting process.
- Standard fluxes are limestone and dolomite but certain other fluxes such as fluorspar may be used in special circumstances.

Limestone

- Calcium carbonate which reverts to CaO (lime) and CO₂ in the cupola.
- The CaO (lime) combines with the impurities to give a fluid slag.

Dolomite

- This is the double carbonate of calcium and magnesium which calcines to CaO and MgO to form a fluid slag with the impurities. The melting point of the double carbonate is somewhat lower than CaO and gives more flexibility with “sticky slags” of high acidity or basicity.
- Both limestone and dolomite should contain a minimum of 96% CaCO₃ and MgCO₃.
- Size range should be 2.5 cm to 7.5 cm.

Amount

- Normal cupola practice requires the flux to be 3–4% of the metallic charge.
- This should provide a fluid slag with a basicity, in this case an acidity of 0.6–0.8, using the standard formula $\text{CaO} + \text{MgO}/\text{SiO}_2$.
- It is extremely important to obtain a fluid slag in acid cupola operations.
- Too little flux will give a highly acid viscous slag which in extreme cases can cause bridging.
- Too much flux will tend to give a basic slag which will quickly neutralise itself by attacking the acid refractory lining resulting in a large slag volume and misuse of energy in the form of coke.
- As there are very few basic lined cupolas in operation in Europe, or the rest of the World, there is little or no point in discussing the operating parameters for basic slags.

Fluorspar (calcium fluoride)

- Fluorspar may be used in small amounts as a slag fluidiser or to reduce sulphur pick-up.

- It is a very vicious slagging material and will severely attack acid linings.

Control

Limestone and Dolomite

- Specify high purity limestone and dolomite.
- Specify and check the size range.
- Weigh or check by volume the amount per charge.
- Remember too little limestone can mean cupola problems.
- Too much is a waste of coke and refractories.

Fluorspar

Briquettes are recommended for acid lined cupola operation. Specify size of briquettes and ensure the correct number per charge is made.

e)Inoculants

The most commonly used inoculants are high silicon materials (ferro silicons and calcium silicide) and high purity highly crystallised graphite.

Silicon based inoculants require the presence of small amounts of minor elements such as aluminium, barium, calcium, cerium or strontium to obtain maximum effect.

More has been written about the effects of inoculation than practically any other metallurgical problem.

Inoculation gives the following advantages and disadvantages:

- reduces tendency to chill and promotes graphite formation
- reduces formation of fine graphite and associated ferrite
- promotes uniform structures
- increases strength
- enables high strength, low carbon equivalent irons to be cast free from chill
- increases tendency to unsoundness.

Size range

- Silicon inoculants – granules 2–12 mm
- Graphite inoculants – powder or fine particles

Control

- Specify requirements and ensure that each delivery conforms to specification, including grading.
- Store materials under cover in an area free from damp or in a waterproof container.
- Finely divided graphite absorbs moisture.
- Silicon inoculants react with moisture which reduces their efficiency and makes them dangerous in use.
- Segregate each consignment in case of variations or problems.

Using Inoculants

- Weigh each inoculant addition.
- Add it at the last possible moment before casting.
- Ensure uniform distribution throughout the metal.
- Add the inoculant to clean metal free from slag or dross.
- Ensure good mixing. Add inoculant to the metal stream or to a partly filled ladle.
- When using transfer ladles, add inoculant to the casting ladles as above.
- Do not delay pour. Inoculants are subject to fade, in most cases over a very short period of time.
- Use late stream or mould inoculation where possible.
- Where possible use inoculant in the form of a wire as a late addition to the metal stream.

Alloy Additions

- Electric furnaces, cupolas or cupola ladles.
- The specification of the desired cast iron will determine the production route.
- In general, highly alloyed irons – Ni hard, Ni resist, high chromium and high silicon irons – are made in electric furnaces.
- Low alloy grey or ductile irons can be made in either electric furnaces or cupolas.
- Alloy additions used to provide the alloying elements and their recovery in cupola and electric furnace practice are given in Exhibit O.

Control

- All alloy additions should be accurately weighed.
- Ladle additions should not exceed a total of 1% unless the alloy addition is of a low melting point or is absorbed very easily. Metal temperatures should be as high as possible when addition is made.
- Avoid the use of alloy scraps which can give rise to obnoxious fumes or gases

- Avoid the use of relatively low cost alloy scraps which contain elements deleterious to the alloy cast iron being manufactured.
- Specify requirements, type, chemical composition, size range and check each consignment.
- Segregate each consignment.
- With high alloy cast irons it is necessary to check chemical compositions of the molten metal by spectrograph and adjust before tapping.
- A summary guide to maintaining quality in foundries is given in Exhibit P. This illustrates some of the major problems which can occur if strict quality control is not carried out.
- Remember that “quality assurance” is not just two words, it is a way of life which encompasses the whole of the business. Quality is only as good as the weakest link in the chain.

f) Weighbridge

Large and medium-sized foundries should have their own weighbridges to weigh accurately all incoming and outgoing materials, whereas small foundries may have to share a facility with a nearby large company or use a public weighbridge close to the plant.

The weighbridge should have a deck size suitable for road vehicles, with electronic load cells accurate to ± 5 kg and have provision for checking axle loads. The computer print-out should be accessible to the production control computer system. The types of materials that the weighbridge will be used for include:

- incoming (all metallic, coke, sands, coal dust, bonding agents, ferro-alloys, etc)
- outgoing (finished castings, waste sand, slag, etc)

Foundries must keep close control on the receipt and availability of raw materials within the plant. These controls help to reduce overall costs and identify stock excesses.

g) Stockyard

Foundry stockyards should be concreted areas with adequate drainage and the facility to clean out the individual raw material bays, which will be typically for:

- steel scrap
- cast iron scrap
- pig iron
- foundry returns

- ferro alloys
 - coke
 - limestone
- } if cupola melting

Purchased scrap, pig iron and foundry returns should be stored under cover, organised in individual bays by usage frequency, density, specification, or alloy content.

Stockholding will vary according to the size of the foundry and the space available, but a minimum of three days' supply of all raw materials should be held on site. If space is available, those items subject to price fluctuation, eg steel scrap, should be purchased and stored when prices are low. Each delivery should be from an approved supplier to avoid the need for the checking of each load. However, the quality of materials supplied must be kept under constant review to ensure quality levels do not drop.

Charge make-up can be by a crane fitted with an electro magnet or grab or, in very small foundries, by hand. However, all materials must be weighed and an automatic print-out of the weight of each constituent material should be retained manually or, preferably, on computer for traceability purposes.

For cupola melting, coke and limestone should be stored in separate hoppers and the desired weight automatically dispensed into the charging skip. The coke and limestone should be charged into the cupola separately from the metallic to minimise the crushing and fracturing of the coke and so maintain its optimum size. The metallic skips should be charged alternately with the coke/limestone skips.

3.2 Cupola Furnaces

a) Introduction

Since the first cupola patent was taken out in England in the late eighteenth century, the furnace has remained the predominant melting unit in iron foundries on a tonnage basis. Over the two intervening centuries, the basic operations of coke fired cupola have remained relatively unchanged, although the understanding of the process involved has improved considerably.

The conventional cupola has been perceived as a relatively low cost plant which, particularly for smaller foundries, is capable of achieving the appropriate quantity of iron, especially grey iron. Thus the status of the furnace was virtually unchallenged in iron foundries until the late 1950s, early 1960s.

At that time, electric furnaces, particularly coreless induction types, began to make inroads into the market. This market penetration has accelerated in recent years with the development of more efficient and powerful solid state powered equipment. The introduction of electric furnaces was promoted by environmental concerns, by the

ability to produce more easily a range of alloys, by increasing customer expectations regarding quality, and improvements of both electric furnace equipment and associated refractory systems. Many of the small to medium sized electric furnace plants installed in recent years have been justified on this basis, even though capital costs may be higher than for a simple cupola plant.

The introduction of environmental legislation requiring rigorous control of emissions to the external atmosphere has been perceived to mitigate against cupola melting in favour of electric melting, the latter being considered by most foundrymen to be cleaner. However, this is not necessarily true, since deterioration of scrap quality, the need to control workplace environment and the continued scrutiny and tightening of outside emission limits apply whatever the melting unit. Various recent waste regulations mean that the dumping of waste from furnace emission control systems will become more difficult and expensive, and the use of the cupola to reprocess such material will become a more important benefit in the future.

The largest melting cost item is charge metallic and the ability to process lower quality scrap through a cupola, due to its refining action and greater tolerance of included non-metallic material, is of considerable benefit, particularly for tonnage applications. This is why large tonnage outputs of a restricted range of unalloyed cast irons are almost invariably produced from cupolas. Such plants may include hot blast facilities and will for the most part be fitted with fume cleaning plant of sufficient efficiency to satisfy the appropriate environmental requirements. These cupola installations will employ electric holding furnaces to allow for optimum operation of the prime cupola melter.

Most iron foundries have had to consider either upgrading their emission control equipment or changing their melting practice to ensure compliance with the relevant requirements. The choice in reality has been between fitting dry bag filtration systems or changing to induction furnace operation. These options are expensive, but installing suitable emission control equipment on an existing cupola plant has no economic justification other than keeping the company out of Courts and allowing them to continue in business.

The majority of cupola plants are based on conventional cold blast units, which may or may not be fitted with improvements such as automatic blast control, oxygen enrichment, and divided blast equipment. In addition, the higher output furnaces, especially where long campaign operation is involved, have for many years been largely of the hot blast type. However, relatively recently, the impending legislation on emissions and to a lesser extent waste, the increased interest in long campaign operation and the ever present need to reduce costs – both capital and operating – have all conspired to ensure that cupola technology has not become stagnant. The following sections attempt to review the current status of the cupola furnace.

b) Conventional Cold Blast Cupola Operation

The conventional cold blast cupola is a vertical shaft furnace operating on the counter-current principle. Cold charge materials are fed into the top of the unit and are preheated by the products of combustion of coke as they descend and melt before being tapped out near the base (see Exhibit Q).

An incandescent coke bed is established in the lower part of combustion air (blast air) introduced via a series of tuyeres arranged in this area to ensure that appropriate combustion conditions are generated. Blast pressure, velocity and disposition are important and require adequate control if the correct bed conditions and temperature distribution are to be maintained.

The cupola furnace is not a “dead melting” furnace in that the melting process is accompanied by a number of compositional changes – carbon and sulphur pick-up, and oxidation losses of silicon and manganese.

Pick-up of carbon depends on a number of factors including:

- initial carbon content of the charge mixture
- the tapped silicon and phosphorus levels
- the amount and quality of the coke
- coke bed temperature
- cupola well depth
- method of tapping
- metal tapping temperature.

Clearly some of these factors are inter-related.

Sulphur pick-up in turn is governed by a number of factors, notably the sulphur content of the coke, slag basicity and charge make-up and composition.

There is invariably some oxidation loss of silicon during cupola melting, normally between 10% and 20% of the charged level of element. The actual figure will vary depending on the melting conditions, with high tapping temperatures favouring a reduction in losses and the presence of steel scrap and high silicon briquette additions having the opposite effect. Manganese is subject to oxidation losses of the order of 20–25% of the charged level, although again melting conditions will have an influence on the practical values achieved.

The cupola is refractory lined and as the melting campaign proceeds, the refractory is mechanically and chemically eroded until the remaining thickness is insufficient to allow for continued safe operation. This erosion situation limits the melting campaign and

usually requires the provision of two furnaces in an installation. One will be melting while the second unit is being repaired. Eroded lining material, together with coke ash, dirt from the charge materials and appropriate fluxes (usually limestone) results in the formation of an acid slag which is tapped either with or separate to the metal.

From the above, it can be observed that there are a number of areas of possible improvements that could be explored when considering the limitations of the conventional cold blast cupola. These include:

- increasing coke bed and metal tapping temperatures
- improving carbon pick-up and reducing sulphur pick-up
- reducing silicon manganese oxidation losses
- increasing campaign length
- increasing melting rates.

In addition, the increasingly stringent emission and waste regulations have resulted in the development of re-use systems to minimise their effects on the foundry's operations and costs.

These factors have resulted in considerable research and development of a wide variety of cupola technology in an effort to improve the performance of the furnace.

c) Divided Blast Cupola

The divided blast cupola, a development of the balanced blast cupola of earlier years, was developed in the early 1970s and became very popular as a means of improving the performance of many cold blast cupola plants installed years before and struggling to meet increasing quality standards. It also became popular in new installations at that time.

In the balanced blast system, however, the cupola is provided with two rows of tuyeres set 900 mm apart and the air blast is controlled in both areas. A distribution of 50/50 between the two rows of tuyeres appears to give the best results independent of the amount of charge coke or blast rate. Control can be obtained by using separate fans for each row of tuyeres or by installing proportioning control equipment in the ducts from a single fan (see Exhibit R).

The system enables a higher metal tapping temperature and higher carbon pick-up to be obtained for a given coke charge **or** a reduction in charge coke and an increase in melting rate whilst maintaining a given tapping temperature. It is necessary to recognise that all of these advantages cannot be obtained at the same time.

Exhibit S shows the relationship between coke consumption, metal temperature and melt rate.

The divided blast cupola may be further enhanced by the use of oxygen applied to the lower row of tuyeres.

d) Hot Blast Operation

Hot blast operation involves preheating the cupola blast air and was originally conceived as a means of reducing coke consumption. It was first adopted for foundry use in the late 1940s, early 1950s and by heating the blast air to about 500°C, charge coke reductions of about 30% were experienced compared to cold blast operation. However, hot blast could also be employed to increase metal temperatures and carbon pick-up and this permitted the use of more steel scrap in the charge mixture.

The advantages of hot blast operation may be summarised as follows:

- reduced coke consumption
- increased metal temperature
- higher melting rate
- reduced sulphur pick-up
- lower melting losses of silicon
- increased carbon pick-up.

It is not possible to obtain all of these benefits simultaneously.

Hot blast cupolas have not been universally used in all European countries but have been very popular in Germany. In many countries initial environmental legislation was more stringent for hot blast cupolas than for cold blast. This is not the case now and the cost of the recuperator is relatively easy to justify on operating cost savings.

Most hot blast cupolas are operated on long campaigns, many with externally water cooled unlined shells in the melting zone. Several of this type of furnace have been used for the production of low sulphur ductile base iron using basic slags.

Blast heating has been carried out using both independently fired and recuperative hot blast systems. However, the high fuel costs and generally poor performance of the independent units has resulted in recuperative systems incorporating combustion of the cupola off-take gases being the most common arrangement.

In recent years there has been an interest in the use of higher blast air temperature in excess of 700°C. Such very high blast temperatures will result in further enhancement of recarburisation of the iron, while the lower blast rates for a given melt rate and the higher bed temperatures should allow the use of smaller charge pieces such as borings to be successfully melted. It has been suggested that superheated hot blast systems will

allow lower grade, smaller coke to be employed without the tapping temperature decrease, which would be experienced with conventional cupolas.

e) Oxygen Enrichment

Although the benefits of oxygen were known for a considerable time, it was only in the 1970s when the costs of bulk oxygen, pig iron and coke were such as to make its employment economical that it came into common use.

Compared with conventional operation, the continuous use of oxygen resulted in:

- higher metal temperatures and carbon pick-up and lower silicon losses at the same coke levels – allowing metallic charge costs to be reduced by pig iron replacement and a reduction in silicon additions
- reduced coke consumption for a given temperature
- improved tapping temperature recovery at a start of melting or following shutdown periods.

The oxygen could be introduced by three different processes – blast enrichment, tuyere injection, or well injection – in order of increasing effectiveness. However, blast enrichment was simpler and the majority of cupolas adopting oxygen technology employed this system.

More recently, the use of supersonic oxygen injection into cupolas via the tuyeres is becoming an accepted technique and a number of cupolas in Europe have installed such facilities. In this process the tuyere lance nozzles are specially designed to provide an outlet velocity in the range 2–2.5 Mach. It is claimed that this approach results in better oxygen and air blast penetration with a consequent improvement in coke bed temperature.

The injection lances are self-cooled by gaseous oxygen and are mounted centrally in each tuyere (generally tuyeres are water cooled) at a distance of between 100 and 300 mm from the exit. It is claimed that the following effects result:

- blast volume is reduced
- blast air/oxygen distribution is more uniform and furnace internal pressure is reduced
- heat losses from cupola are reduced due to more even coke bed combustion
- charge preheating is improved because there is less temperature variation over the cross-section of the cupola
- charge coke additions are reduced
- melting rate variations of -50% to +40% of nominal melting rate are possible

- furnace shell losses are lower as higher temperatures are achieved in the centre of the cupola
- metal tapping temperature is increased
- silicon losses are reduced
- the blast temperature on hot blast cupolas is increased by the higher off-take gas temperature.

It is also claimed that the process is the first oxygen method which demonstrates a reduction in coke consumption at a constant melting rate such that coke savings fully compensate for the cost of oxygen. It is further suggested that it should be possible to use lower grade coke with consequent further cost savings.

f) Long Campaign Cupolas

In recent years there has been considerably increased interest in operating cupolas for extended periods, both on a daily basis and also from a refractory campaign point of view (repair after weeks rather than after melting day).

Obviously the well-established hot blast technology already discussed in an earlier section can fulfil this role successfully, However, largely as a result of work in the USA, a number of cold blast units has been adopted for the same purpose.

The cold blast furnaces include similar features to those found in hot blast plants in that the cupola shells (which may be lined or unlined) are fully water cooled and are fitted with water cooled projecting tuyeres. Tuyere blast velocities are considerably higher than conventional cold blast practice to ensure complete penetration of the coke bed, the generation of very high bed temperatures and a minimisation of heat losses, particularly through an unlined shell.

Metallurgical Automobile Recycling Plant

The use of cupola plant for recycling considerable quantities of steel scrap containing non-metallic material is not new. However, the use of cupola technology as the heart of an integrated reprocessing system for automobile body shells would result in a low cost bulk metal supply route for large foundry operations where there is a readily available source of suitable feedstock.

Over recent years the increasing pressures to reduce waste and improve reprocessing opportunities has resulted in many automobile manufacturers claiming a higher degree of recyclability for their products. This, together with increased use of valuable recoverable material, is likely to lead to more selective dismantling. Nevertheless, significant quantities of organic materials in the form of paints, lubricants and plastic

components and the trim are likely to remain in the resulting car body shell. Zinc coated steel will almost certainly feature in the body construction, while wiring looms and electric motors may be a source of unwanted copper contamination unless removed prior to reprocessing. Car body shells can be prepared by either baling or fragmentation. Fragmentation scrap with appropriate magnetic separation and screening can be rendered clean and at adequately low levels of contamination. However, its generally small size and thin section do not make for an ideal cupola feedstock. Newer, modified cupola techniques to avoid excessive oxidation could improve this situation and lead to greater acceptability.

Baled scrap from known sources has been fairly widely used for cupola charges, although in smaller furnaces the tendency to scaffolding problems has limited its use. The use of hot blast and a tapered shell arrangement will alleviate the scaffolding difficulty and reduce oxidation problems with such feedstock.

g) Ancillary Equipment

Environmental Control

The design of effective emission control equipment for cupolas is more difficult than for other foundry processes due to the wide range of gas temperatures (100–1200°C), particle sizes (<1 mm to 10 mm) and flow rates involved. In addition, the presence of sulphur dioxide can cause corrosion problems and any combusted volatile matter may create condensation difficulties with filter media. The high levels of carbon monoxide can be hazardous and unacceptable from a discharge point of view unless burnt.

Most modern emission control plant for cupolas is based on the use of dry bag filter systems. Cold blast operation can result in effluent gas temperatures which vary during the campaign and are generally well in excess of that capable of being handled by economical fabric filters. Gas cooling is therefore required to prevent damage to the filter bags. However, too low a gas temperature may result in condensation of both volatile matter and water vapour leading to adverse effects on plant performance. These include blinding of the filter fabric, corrosion problems in the plant itself, and risk of fire or explosion damage due to flammable deposit ignition.

In order to heat the blast in hot blast cupolas, the off-take gases are burnt in a recuperator but the system actually used may vary depending on the condition of the gases to be handled.

Dust and Waste Injection Systems

Much research and development effort has been expended over the years in attempting to perfect methods for introducing particulate materials in cupolas and these can be categorised as follows:

- exploitation of swarf and borings
- concentration of metallic elements, in particular zinc, for subsequent recovery
- recycling of waste materials such as collector waste, used sands, etc.

Most injection systems have been based on lancing systems incorporation in the tuyeres but it has been found that the cooling effect involved has restricted the opportunities for significant continuous injection because of the need to melt the material collected in the coke bed. It is, therefore, of considerable interest to increase the continuous injection rates and to establish practical feed rates for various waste materials.

Some work undertaken in Germany has been carried out using oxy-fuel burners in the tuyeres of a hot blast cupola. The technology should be transferable to most types of cupolas.

A mixture of natural gas and oxygen is supplied to the burner with dust being injected through the burner pipe from a specially designed transporter unit and ejected through the burner outlet.

Oxy-fuel burners result in very high flame temperatures compared to fuel-air systems, since no nitrogen has to be heated.

Each type of particle influences the overall melting process in a different way, for instance the carbon containing flue ash/cupola dust acts as a supplementary fuel. In these trials the injection rates were restricted by iron quality considerations rather than blockage of the coke bed in front of the tuyeres.

Other advantages of tuyere oxygen injection, such as charge coke reduction, reduced blast air requirements, better carbon pick-up and metal temperatures can be achieved by use of the burners when injection is not being employed. This makes for increased furnace flexibility. Recycling of dry bag filter dusts by cupola injection can result in the concentration of zinc such that it can be sold to a zinc reclaimer.

Waste Heat Recovery

The exhaust gases leaving a cupola are at a high temperature and contain combustible elements which could be exploited as an energy source. Clearly this energy is utilised in hot blast cupolas to good effect but even in these cases less than 50% of the energy available is employed.

The available waste heat could be used for a variety of other applications by employing suitable heat exchanger systems. Indeed a few examples do exist of hot water and steam production for space heating and process heat. Space heating and hot water production for ablutions and other uses may not be required consistently but one interesting example of a process heat application is for steam generation to power an electricity generating set and compressor. Foundries usually require both electricity and compressed air during their operating hours and therefore there is a continuous outlet for the waste heat from the cupola plant. It is claimed that the use of this system on a 50 tonnes/hr hot blast facility results in an energy utilisation approaching 100%.

Other possible applications of cupola exit gas energy could be for charge material and coke drying and preheating duties to prevent condensation in bag filter outlet chimneys, dust extraction systems and shake-out drums.

The need for high efficiency gas cleaning equipment on modern cupola installations provides the possibility of waste heat recovery, which requires evaluation.

3.3 Coreless Induction Melting Furnaces

a) Introduction

Coreless induction furnaces have been used in the ferrous industry for over 50 years and are now one of the most popular means of melting and holding ferrous materials. The coreless induction furnace comprises a relatively thin refractory crucible encircled by a water cooled copper coil excited from a single AC supply (Exhibit T). When the coil is energised, the fluctuating axial magnetic field causes a current to flow in electrically conducting pieces of charge material within the crucible. The power induced in the charge depends on the physical properties of the material, the flux linking it and its geometric shape.

Dependent on the resistivity of the material being melted, the coreless induction furnace converts electrical energy to heat in the charge at an efficiency of between 50% and 85%, although furnace efficiency is further reduced by thermal losses from radiation from the melt surface and conduction through the furnace lining.

Once molten, the interaction of induced currents with the electromagnetic field causes forces to be applied resulting in a stirring action as shown in Exhibit U. Empirically, the stirring forces are proportional to the power divided by the square not of the operating frequency. Thus for a mains frequency furnace, the stirring forces are approximately 4.5 times those at 1,000 Hz for a given power density. In recent years, the attainable power density has reached a level of 1 MW per tonne capacity.

The furnaces can operate at mains frequency (50 Hz) or, as is the common practice with most new installations today, medium frequency, typically 200–1,000 Hz.

The major advantage with coreless induction melting is that there is greater flexibility in the types of irons that can be melted when compared with cupola melting. Other advantages are that in many cases the iron can be poured into moulds without duplexing and pouring temperatures can be accurately controlled and adjusted to suit particular casting applications. The fumes generated from electric melting operations are much less and easier to handle than emissions from cupola melting.

Refractory selection for iron melting is normally limited to rammed silica materials, although alumina and/or a combination of alumina and silica are sometimes used.

Materials are rammed around a former to form a monolithic lining. Selection of scrap material is more critical than with cupola melting in that scrap needs to be clean, dry and free from other contaminants. The furnaces generally require a higher level of specialist skills for maintenance in the fields of electrics and hydraulics.

The mains frequency furnace offered a relatively inexpensive coreless melting unit. It was essential to maintain a heel of molten metal in the furnace during the working day to achieve an acceptable performance. This restricted its economic use to two or three shift operation. Large capacity furnaces were necessary for modest melting rates. After the initial start-up cycle of four to six hours, it was necessary to retain a good molten heel. Only in this way could full rated power be applied and maximum melting rate achieved. Naturally, this represented a high energy wastage in simply maintaining a molten heel.

The mains frequency furnace and the tripler (150 Hz) offered the iron founder an effective means of producing grey iron from steel scrap or reclaiming cast iron borings. The tripler was ideal for melting alloy iron for the small jobbing foundry operating on a single shift basis, whilst the mains frequency furnace was the perfect tool for recovering swarf or low grade, but clean scrap.

Over the past 20 years, medium frequency furnaces have superseded mains frequency and tripler units as a result of the development of thyristor technology. The solid state power supply (inverter) uses a combination of thyristors and diodes to convert a 50 Hz input to a higher frequency output. For a given power input, an increase in frequency reduces the meniscus height and hence power density may be increased by up to four times. Capital costs of coreless furnace melting equipment have been reduced by a combination of smaller furnace body sizes and lower power supply costs and, in addition, furnace control has been dramatically reduced.

Inverter power sources are designed to allow the output power frequency to alter in order to maintain tuning to the natural frequency of the coil system. Thus, capacitor switching is eliminated and the power applied to the furnace is dependent solely on the limits of current and voltage within the inverter, these being chosen to allow constant power input to be achieved throughout the melting cycle. In practical terms, the furnace operator can adjust power with a simple variac control.

As a non-conducting lining material is normally used, the metal is the hottest part of the furnace and the temperature control becomes a simple operation with no overshoot when power is switched off. However, because of the high power densities which can be applied in medium frequency furnaces, superheating rates as high as 40°C per minute may be experienced. It follows that good operator awareness is mandatory and dip pyrometry is strongly recommended in order to avoid excessive melt temperatures.

The medium frequency furnace has many advantages over mains frequency devices. In addition to power density increases and stepless power control, smaller piece sizes may be melted from cold, offering an efficient batch melting unit. This provides a significant energy saving, especially when single production shifts are operated.

The operating frequency is selected to be appropriate to the typical charge material to optimise furnace performance. The furnace and inverter are of compact design and occupy far less space than mains frequency equipment.

A great majority of coreless furnaces in use are of the conventional tilting type. A pair of hydraulic cylinders are normally used to tilt the furnace about an axis passing through or adjacent to the pouring spout. When pouring into a transfer ladle, variations in the metal stream are of no consequence as the furnace tilts through a full 95 degrees to the empty furnace position. Coreless tilting furnaces varying in size from 25 kg to 20,000 kg with melt rates up to 20 tonnes/hour are in use.

b) Furnace Operations

➡ Coreless Mains Frequency

Coreless mains frequency furnaces can be used for melting grey, ductile, malleable, alloyed irons and steels, but will require different refractory types to suit the alloy being melted. For the cast iron family in general where melting temperatures will generally be below 1600°C, silica refractories will be used.

For alloy irons, or where temperatures of the metal exceed 1600°C, it is normal to use a rammed alumina refractory. For steel melting at elevated temperatures, magnesite is normally used.

The melting rate depends upon both the size and power ratings of the furnace, but in general compared with medium frequency furnaces, the melting rate is fairly slow, eg a 6 tonne capacity 1500 kW furnace will have a production rate of approximately 1.5-2.0 tonnes per hour.

Mains frequency furnaces are normally operated on a tap and charge basis, i.e. the furnace is never completely emptied of molten metal whilst it is in use, typically between one-third and two-thirds furnace capacity is maintained as a molten heel. The furnace can then be charged with cold scrap and a higher power input can be applied and a faster melting rate achieved than if the furnace was completely emptied. Obviously, where a furnace is used in a duplexing operation and is charged with molten metal, this practice is invalid.

Start-up from cold can be slow with a mains frequency furnace because it is impossible to induce high power unless the furnace is densely packed with its charge material. A starter plug that will have been cast into a mould to produce a fairly close fitting shape of the bottom of the refractory crucible will first be loaded into the furnace. The starter plug will be produced in an iron compatible with the normal charge materials and represent 20–25% by weight of the furnace capacity. The remainder of the charge is packed tightly into the furnace and the balance retained to be added as melting commences.

The power input from start-up has to be progressive from the lowest transformer tap, such that a temperature increase of between 150–200°C per hour is achieved. Under these conditions it can take between four and six hours to complete the initial melt of a 6 tonne furnace. With such a steady melting rate, the furnace refractories are given a good opportunity to pass through the expansion phases carefully up to their designed operating temperature and this enables thermal cycle cracks to close up and seal the refractory crucible before melting commences.

➡ **Coreless Medium Frequency**

Medium frequency furnaces can be used for grey, ductile, malleable, alloyed irons and steel, but offer a greater degree of flexibility to foundries producing more than one type of ferrous material. Providing that furnace refractory cleanliness is taken into consideration it is possible to change metal type with each furnace melt, providing that the refractory chosen is suitable for the melting temperature.

The melting rate of these furnaces can be quite high and modern designs are generally capable of melting their capacity within one hour, eg a 6 tonne capacity 4000 kW medium frequency furnace melting with a hot lining could be completely melted, analysed and ready to pour within 60 minutes.

Medium frequency furnaces are normally completely emptied between melts with the cold charge materials being directly added to the empty furnace. Full melting power is then applied and the solid state circuitry regulates power to ensure that maximum melting conditions are maintained through the cycle.

Starting up from cold, unlike mains frequency, does not require a starter plug and normal charge materials can be directly added to the furnace. The power input is controlled during the cold start melts to prevent thermal shock to the lining and the premature melting of the charge before lining cracks have sealed. Both types of coreless furnace are prone to a condition known as “bridging” whereby the charge material locks in the furnace and does not fall into the molten pool below. Under these circumstances the molten pool can rapidly exceed the safe working temperature of the refractory, resulting in a failure of the refractory and the possible loss of the furnace. Furnace operators should be constantly aware of furnace bridging, particularly with medium frequency units, where the temperature rise in the molten pool is extremely rapid.

Smaller furnaces are more prone to this condition with use of oversize scrap. The coreless induction furnace lends itself well to the melting of cast iron borings and swarf. The inherent stirring action generated by the magnetic field allows the efficient melting of these materials.

➡ Charging Methods

Charging methods for coreless furnaces will depend upon several factors:

- furnace size
- furnace throughput
- charge materials used.

Both mains and medium frequency furnaces can be charged by mechanical or hand methods, but the points above will normally dictate the method. For magnetic materials such as steel scrap, pig iron and foundry returns, overhead cranes fitted with electromagnets can be used for both charge make-up and direct charging of the furnace.

Hand charging or direct charging are only really suited to smaller furnaces. Where throughputs are high or the operating conditions are difficult, charge materials can be added to the furnace by drop bottom buckets or vibratory chargers, which will often incorporate weighing devices to ensure correct charge make-up.

Where non-magnetic materials are being charged, such as austenitic irons, the most common practice will be by hand or the mechanical devices described before if volumes are high.

➡ Deslagging

The slags generally developed in coreless furnaces are not fluid as with cupola melting, but quite heavy and sticky and often dry and in the form of a dross. Removal of the slag therefore is generally facilitated by the use of deslagging spoons which are proprietary items produced in a graphitic moulded refractory or by the simple use of steel bars. The methods used will depend upon furnace size and can be mechanical grabs where the surface area of the bath and slag volume is large.

For larger furnaces back tilting has been introduced. If slag coagulants are used to aid the removal of the slag, their use should be strictly controlled to prevent chemical attack of the furnace lining material.

Slag volumes can be reduced by selecting clean charge materials.

➡ Charge Pre-Heat, Preparation and Handling

In theory, the melting efficiency of all types of furnaces can be improved if the raw charge materials are subjected to pre-heat. In practice charge pre-heaters are generally not used by foundries using electric melting.

Medium frequency melters do not benefit from pre-heat to the same degree as mains frequency when energy cost considerations are taken into account.

Scrap for electric melting should be clean, dry and free from oil, grease paint, rust and large amounts of adhering sand. Where baled steel scrap is used care should be taken to ensure that non-metallic or crushed aerosols are not included. Baled steels should also be checked to ensure that pre-coated steels such as tinned plate and zinc coated are not included, because these materials can produce excessive amounts of metallurgical fume and slag. Where use of these materials is necessary, fume cleaning will be required.

In many foundries running systems are shot blasted to remove adhering sand and hence add to furnace cleanliness and melting efficiency.

Charges will need to be pre-weighed and stored in suitable containers ready for charging by the chosen method.

Carbon in the form of graphite (crushed electrode) or petroleum coke and ferro alloys are normally added throughout the metallic charging period to improve mixing and reduce the amount of trim additions to be made to the fully molten bath. Mains frequency furnaces melt with a vigorous stirring action, which greatly aids the late addition of alloying elements. Medium frequency furnaces by contrast exhibit less

vigorous stirring action as the operating frequency increases, which in turn makes the addition of alloys and particularly graphite to the fully molten bath more difficult.

➡ **Metal Losses**

Metal losses for metallic charge materials will depend upon the physical size of the component, but are normally less than 5%, with a fair proportion of this loss being due to spillage and splash during the deslagging and pouring operations. The recovery rates for alloy additions such as ferro-silicon, ferro-manganese, ferro-molybdenum, etc, vary between 90% and 95% of the available element contained. Additions of carbon in the form of graphite will depend on the furnace type as described before, but can be expected to be within a band of 85–95%.

c) Coreless Furnace Process Control

The modern concept of melting shops involves control of all of the functions taking place so that a detailed knowledge of liquid metal quality and costs can be gathered. Previously, only the larger melting shops with multiple high powered furnaces had a form of furnace control. However, the low cost of computers and programmable logic control (PLC) devices now allows control systems of varying degrees of complexity to be economically installed in smaller installations. These systems perform several functions which can be classified under the headings of process automation, process monitoring, documentation for records and interfacing between other furnaces and control systems.

➡ **Process Automation**

The most advanced systems can control the melting cycle from the selection of charge through to tapping and interfacing with other management systems. Simpler systems only control the melting operation itself.

To function they need information on charge weight, time and power input. The charge weight is obtained from load cells or input from the operator while time is known from the device's internal clock which is reset at the start of each melt. Power is derived from the voltage and current measurements for the furnace coil. The energy input is then calculated and compared with a set value which is determined from the manufacturer's experience with similar furnaces and can be altered by the operator to account for individual circumstances. When the set value is reached the furnace is automatically switched off and the charge will be molten at about the target temperature. Measurement of these parameters is reasonably accurate, however variation in the charge and how it lies in the furnace results in varying induced energy so that the temperature obtained alters between melts. The next stage is to superheat the metal to the set tapping temperature which can only be achieved if the starting temperature is

known. This is provided by ensuring that an accurate metal dip measurement is taken, with the result either being directly fed to the control system or entered by the operator.

Between melting and superheating, the metal is normally deslagged, sampled and composition altered to meet specification. If required, the control system will hold the temperature at any set value and calculate the optimum power level to do it. In this way an accurate control is kept on the energy supplied, avoiding high energy cost and excessive temperature.

The control systems can be used for other automatic operations:

- cold starting furnace
- sintering of a new lining.

In the above cases temperature data is provided by thermocouples and the system controls the temperature by varying the power input.

➤ **Process Monitoring**

While controlling the melting operation, the system can also monitor the auxiliaries such as water, hydraulics, power supply and fume extraction system. When a problem occurs, an alarm display alerts the operator. A long term record can be kept of the coil current and its trends at a particular voltage as any increase may indicate lining wear. Therefore, the system can give the operator an indication when the refractory needs replacing.

➤ **Information Display and Recording**

The control system provides information and the more complex do it at all levels from operator to management. A VDU display gives information on energy consumption, power, temperature and metal weight in the furnace during melting, holding and superheating. The data is often shown in a graphical form to assist in reading the information. There are different menu screens for different functions, for example, to indicate alarms, to fit the lining or to tap. A slave monitor can duplicate the display away from the furnace platform. The simpler systems may have an LCD display which will provide the same general data but not graphically.

The operator can communicate with the system to input information or alter the settings, with keypads, light pens or touchscreens depending upon the manufacturer's preference and the sophistication of the system. Records can also be provided on a heat, shift or monthly basis.

➡ **Interfacing with Other Furnaces and Systems**

Systems are also designed to control melting operations with more than one furnace. The system then controls all the furnaces and optimises the melting to give the required metal output from the whole melting installation. It will take account of the power limitations imposed at some periods of the day by the contract with the electricity suppliers and optimise the melting to give the best melting rate.

Systems have also been developed to report to and receive information from a control network operating at a higher level. It can act on information from the network such as a change to metal pouring temperature, change in alloy composition, raw material availability and charge weight and operate the furnaces accordingly.

➡ **Summary**

These control systems are a method of providing automatic control of melting, holding and tapping. They can start the furnace from cold, control the lining sintering cycle and make a continuous diagnostic check on the power supply, the furnace components, the auxiliary systems and the furnace lining. Any fault or failure can be identified and drawn to the attention of the operator. Comprehensive records can be kept of all the data monitored for management control. The systems can control more than one furnace and be part of a larger network controlling all the functions of the melting shop. The foundryman should discuss his requirements with the manufacturer before deciding which system to buy. The most sophisticated systems are not cost effective for the small foundry. Some systems can be retro-fitted to existing equipment.

3.4 Channel Induction Furnaces

a) Introduction

Many large and medium sized foundries use mechanical methods of mould production and therefore require a continuous supply of molten metal to optimise production. Quite often the demand for metal will fluctuate throughout the production day and be beyond the physical and economical constraints of the melting plant. In these circumstances the foundry will require a buffer in the metal supply and this is where the channel holding furnace comes into play. Channel furnaces, therefore, often complement a cupola or coreless furnace prime melting operation. In some instances, where off-peak melting is carried out, the vertical channel furnace can become the prime melter and holder.

The main disadvantages are the requirements for dry, very clean charge materials, the difficulty in removing slag from the large surface area of the bath and the poor stirring action which make alloying additions difficult. Energy consumption for melting is very

high, typically in excess of 1,000 kW/tonne when allowing for the energy demand during non-productive periods.

b) Basic Description

A channel furnace comprises a bath of molten metal to which is connected a molten metal loop contained within an inductor box, which also houses the power coil. The channel furnace works on a transformer principle. The multi-turn power coil is wound around one leg of a lamination to form the primary circuit of a transformer, whilst the loop of metal acts as a single turn secondary.

The close coupling between the induction coil and the metal loop provides a higher natural power factor than occurs with the coreless induction furnace and the efficiency of converting electrical energy into heat in the metal is therefore also higher, being approximately 95%. The molten metal loop needs to be continuous and is not allowed to solidify in case this continuity is broken during contraction. The loop is contained by refractory, usually enclosed within a rigid steel inductor box which can be separated from the main furnace body to allow refurbishment of the inductor box refractory. To mechanically support the refractory between the loop and the induction coil, a split water cooled bushing is interposed.

The cooling system is designed to produce a steep thermal gradient in the refractory, improving its integrity.

Channel furnaces are manufactured in three different configurations, namely vertically, drum and bath type. They can be used for melting, holding and/or duplexing, although generally the drum and bath type furnace have been used for holding whereas the vertical channel furnace has been used for melting.

c) Vertical Channel Furnace

Because of its design configuration (Exhibit V), this furnace can be used as an efficient melter. It gained popularity about 25 years ago, as an off-peak melter for the production of relatively large castings of grey iron. It uses low cost electricity during off-peak periods and stores relatively large volumes of metal for pouring as and when required. Unfortunately, as the cost of electricity has increased due to the fact that the furnace needs to hold metal 24 hours per day, 7 days per week, it has been found to be uneconomic in most foundries.

The original design concept has been changed somewhat to work as a duplexing furnace where metal is transferred from the prime melter, normally via a launder, whilst pouring to the ladles as and when required.

d) Drum and Bath Type Furnaces

These types of furnaces are commonly used as holding furnaces and duplexed in conjunction with a cupola (Exhibit W).

Molten metal is normally transferred via a launder or in some instances by ladle to the furnace where it is held and superheated as required. It is well insulated so that its holding power is as low as practically possible, since this furnace also needs to hold molten metal continuously.

Unlike the drum furnace, the bath tub type has a removable roof for maintenance purposes, although this reduces the overall refractory life of the furnace.

In the last decade, the use of channel furnaces for melting and duplexing has declined, mainly due to their high operational costs. The large coreless furnace is now being used for holding and duplexing purposes due to its improved operational efficiency brought about by change in coil configuration.

e) Duplexing

Used in its most common mode where metal from the prime melter is fed directly to the fill bowl of the furnace, usually continuously, and metal is taken from the pouring spout to the moulding line simultaneously, the channel furnace offers the ability to ensure good control of both pouring temperature and metal chemistry. The duplexing operation smoothes out variations in the chemistry of the metal from the prime melter and, relative to the furnace size, consumes a low level of power per tonne throughput.

Channel furnaces can normally be operated safely for a minimum of 12 months before refractory repairs necessitating furnace shutdown are required. If careful control of the furnace is maintained and data is recorded with regard to inductor conditions and furnace shell temperature, the furnace can be operated well beyond the 12 month period.

It is extremely important to ensure that the metal supply to the inlet spout is kept as clean as possible to prevent slag reaction with the furnace refractory, which can both shorten the furnace life and lead to problems or blockage in the inlet and outlet spouts. In severe neglect cases this can cause the inlet of the furnace to become completely blocked and require the use of oxygen lances to reopen the inlet.

Monitoring of the furnace body temperature in addition to the water cooling circuit temperatures will give a good indication of the refractory wear to the furnace body. This

check, in conjunction with inductance and monitoring for the inductor, is essential if trouble free operating is to be maintained. Trouble free operation is vital with channel furnaces because failure of the inductor or furnace body can render the furnace out of commission for a minimum of 10–14 days.

f) Melting

For foundries using vertical channel furnaces to produce grey or ductile irons, where alloy changes are not necessary, it is possible to use the furnace as a prime melter. The charge materials, which are usually foundry returns and pig iron, must be dry and clean to avoid excessive slag formation and the risk of explosion. The furnaces are normally charged from overhead magnet or drop-bottom bucket into the molten heel, which has to be maintained at all times.

It is generally accepted that both inductor and upper case refractory lives will be reduced when this type of furnace is used for melting as compared with duplexing.

g) Alloying

In duplexing operations, channel furnaces are normally sealed to reduce oxidation losses, therefore alloying additions are usually made to the prime melter or the metal stream entering the furnace. In melting operations it is possible to make alloying additions direct to the channel furnace, but the poor stirring action within the bath makes for a very poor recovery rate.

h) Deslagging

In a duplexing mode, channel furnaces are normally operated in a sealed condition to reduce oxidation losses and, providing a clean metal supply is maintained, are not susceptible to slag build-up. However, in the melting mode or in the case of slag build-up, the furnaces are fitted with a deslagging door which, when opened, will allow access to the surface of the molten bath. In most cases it is possible to tilt the furnace body so that slag may be removed from the furnace using slag skimmers. Slag skimmers will usually be made from steel bars and may include graphitic refractory spoons or plates to allow easy removal of the slag, which is normally dry and in a lumpy form.

1) Refractories

The type of refractories vary depending upon the type of induction furnace used. Normally dry rammed refractories are used for the coreless induction furnace. Channel furnaces can either be lined with pre-dried bricks, rammed or castable refractories.

3.5 Electric Arc Furnaces

a) Introduction

Electric arc furnaces have produced steel and cast iron for most of this century, but since the 1960s there has been a revolution in their design and operation. Prior to this, the electric arc furnace was regarded as a relatively high cost, low production device for steelmaking and for melting stainless, tool and other alloy specialty steels. Today the arc furnace is a proven melting tool for common carbon grades and has shown its flexibility and versatility for producing all steel grades

All the main improvements have been as a response to the tonnage steelmakers where the demands for low costs and high outputs predominate. This has resulted in the powering of the furnaces being increased by 2 times over the period with output rates of 100 tonnes per hour and overall tap to tap times of about one hour. Modern high power arc furnaces now have a power density of 900–950 kVA per tonne of metal.

The changes have resulted in low energy and other operating costs, coupled with increased production rates for a certain unit size. The developments have included greater power per tonnage capacity, improved electrical design and operating characteristics.

The foundry industry has no need for these high output furnaces, but they can employ some of the technology to improve their own practice. In Western Europe arc furnaces are generally not used for cast iron melting and are found in the steel foundries which require higher tapping temperatures and metal tapped weights than their iron counterparts.

The following sections deal with the electrical operation, refractory lining and furnace practice. They will deal solely with direct arc furnaces as another type of furnace, termed submerged arc furnaces, are not operated in the foundry industry.

b) Electrical Operation

Traditionally arc furnaces have been powered by alternating current. The arc in the standard furnace is produced in the secondary of a three-phase electrical circuit, between three graphite electrodes and a conducting charge. The arcing between the charge and the electrode raises the charge temperature by passing electric currents through it until it melts. In addition, the high arc temperature results in thermal radiation which also heats the charge, the furnace sidewalls and its roof.

The furnace does not act as a pure resistive load as a voltage between the electrodes and earth must be produced (about 70 V minimum) before an arc is initiated. This electric arrangement is termed an inductive load where the current lags the voltage.

The benefits of lowering the impedance of the circuit are that the furnace operates with higher electrode currents and lower voltage at the electrode tips. This leads to shorter arc lengths which can minimise refractory damage. Along with low impedance, it is important to electrically balance or have power balance at the arc. If the power input is not even at the arcs, then the benefit of high power cannot be realised due to poor refractory life, its excessive premature wear and increased delays due to hot spots on the furnace walls.

The main imbalance in the electrical circuit occurs in the secondary furnace circuit which consists of the conductors from the power transformer to the electrodes and the electrodes themselves. These conductors are flexible cables and their design has improved over the years. Early furnaces had a side-by-side (or coplanar) arrangement of conductors for the three phases. This caused mutual coupling of the electrical fluxes between the centre and the two outside conductors producing an unbalanced electrical load. The unequal length of the cables further increased the imbalance.

Improvements in arc furnace design in the 1960s developed a better balanced secondary circuit. This was accomplished by arranging the conductors in an equilateral triangle configuration so that the flexible cables for each phase are equidistant from each other. Therefore, the mutual coupling between them is similar.

A recent advance is to construct the arms clamping the electrodes, from steel clad in copper. The electrode arms now conduct the current themselves, rather than cables supported by them. A coplanar arrangement is used, but the reactance is less than the triangulated design using cables, although steps have to be taken to balance the inductive reactance of the central phase.

c) Electrode System

The electrodes are a major cost component of arc furnace operation and therefore their care and maintenance is very important. They consist of lengths of specially prepared graphite cylinders which are clamped onto the electrode arms. The lengths of graphite are threaded internally at both ends so that they can be connected together by a threaded graphite section called an 'electrode nipple'.

The arms are supported by vertical beams called electrode masts which are driven up and down by electric motors to maintain the electrode tips a certain distance above the metal surface (the arc length). It is relatively easy to maintain this length when all the charge is melted and a liquid pool has formed. However, the charge moves during melting, increasing the chance of electrode breakage and the electrodes have to be repositioned to compensate and to maintain the arc length. The motors control the arc length according to signals from equipment monitoring the electrical characteristics of the three secondary phases. The clamps that hold the electrodes can be released to reposition the electrodes due to wear or breakage.

With the increase in installed power, the magnitude of the electric current that electrodes have to withstand has increased. Exhibit X gives a general indication of the currents for a range of furnace sizes. One limitation is the current carried per unit area of electrode tip and the 40T furnace, for example, has a maximum of 50 kA in a 508 mm diameter electrode or 247 kA per m².

The furnace transformer has several voltage taps that can be selected depending on the stage in the melting cycle with the higher voltage taps being used at the beginning of the melt and the lower voltage taps after meltdown, during refining and holding.

d) Refractories

The arc furnace consists of a circular or elliptical steel shell in three sections, a disk shaped base, straight sidewalls and a flat or domed shaped movable roof. These sections are refractory lined with materials that will withstand the various conditions experienced in service.

The hearth of the furnace is formed in the base by a combination of bricks next to the steel shell (sub-hearth) and then ramming monolithic material on top. The sub-hearth consists of insulating brick next to the shell, then layers of fire brick and magnesite. The bricks are arranged either in parallel strips across the furnace or in a series of rings starting from the outside and working towards the centre. A magnesite hearth is then pneumatically rammed in using proprietary materials containing a bond for wet

ramming. Burning in the hearth is achieved employing scrap as resistors when electrodes are lowered and powered. The main fritting occurs in the first melt

The life of the bottoms vary from one plant to another but a life of one year or 1,000 heats is achievable. However, very little of the original bottom remains as fettling takes place after each melt to repair any damage.

The sidewall construction has undergone dramatic changes over the years. Traditionally the sidewalls were bricked in a single-step or double-step construction. This method avoids undercutting the sidewall at the slag line or hot spots due to excessive local temperatures. At the slag line, special materials are used to reduce the erosion. Large monolithic blocks made of tapped dolomite have been tried as an alternative to bricks.

Modern furnaces have replaced refractory lined sidewalls with water-cooled copper panels (combi-panels) except for the areas liable to come into contact with the slag. The individual panels are arranged side by side around the wall and the water removes the heat radiation from the melt and electrodes.

A similar development has overtaken arc furnace roofs. They are mainly water cooled and replace the previous brick or monolithic rammed alternative. The area around the posts for the three electrodes is generally still protected by refractory, but in some arc ladle heaters this is also dispensed with.

e) Process

The major raw material for the electric arc furnace is steel scrap, especially in steelmaking, along with returns in the steel foundry. The size of the furnace shell and the amount of power available allows for fewer limitations on the charge with respect to size and quality than electric coreless furnaces.

A melting cycle is started by swinging the furnace roof clear of the furnace body (electrodes have to be raised) and dropping the charge from charging buckets on to the hearth. The furnace volume may not contain all the charge at once so that after melting one batch others need to be added. This back charging requires the roof again to be moved aside and, as the power is switched off for this operation, the number of back charges is kept to a minimum to limit loss in melting time.

Modern arc furnace practice would be to use 'oversized' bottoms for low bulk density charge materials so that all of the required material could be added to the furnace in a single charge. This reduces the 'tap to tap' cycle time considerably.

When charged, the roof is replaced, the electrodes lowered and the power switched on. Arcing occurs between the electrodes and the charge, which is heated and melts to form

a liquid pool in the hearth. While the charge is melting, it is moving continuously, so the electrodes are the most vulnerable to breakage at this stage. In addition, the arc length is varying and the electrodes are continuously being automatically moved by the control system in an attempt to maintain constant arc voltage, current and power.

Modern furnaces use oxygen injection or oxy/fuel (gas or oil) burners as an additional energy source. Such burners can contribute up to 3–5 MW each. The use of these facilities can result in a reduction in melting time of up to 20% and a reduction in the electrical energy and electrode consumption of up to 10%.

Water cooled lances can be employed, again positioned in the slag door or sidewalls, to blow in oxygen and for inject powdered carbon or lime. The object is to increase productivity, homogenise the liquid bath, control decarburisation and optimise a foaming slag practice which is now common as it shields the sidewalls from radiation during the long arc operation. After melting, the liquid metal is sampled and its composition modified or refined to obtain the necessary specification. Refining is accomplished in two ways, either by using a single or double slag process. In the single slag process, lime is added and oxygen injected to reduce the carbon, sulphur and phosphorus content of the bath. For many qualities the steel can then be tapped with composition adjustments being made in the ladle.

The other method involves removing the first slag and making a reducing slag which will lower the sulphur content without influencing the carbon and phosphorus levels. The required metal analysis can then be achieved by alloy additions and the furnace tapped. Historically, this was done by tilting the furnace. However, bottom tapping has been developed with a sliding gate valve controlling the metal flow.

The refining period can be as long as the melting time, which reduces furnace efficiency. Consequently, it is now common for the arc furnace to be combined with a refining unit of which there are several including stirring ladles, arc heated ladles, vacuum ladles (VAD or VOD) or an argon/oxygen bottom blown vessel (AOD).

Waste gases, laden with iron fume and volatile constituents of the melt are vented through a port in the roof into the extraction system. The gases (mainly CO) are combusted, diluted and cooled by air and passed through bag filters before being released into the air.

f) Production Control

In line with most industrial processes, arc furnace melting has become more automated. Computers are able to monitor power input, transformer performance, oxy-fuel burner output and any alarms. The charge make-up with respect to cost and grade can be

determined and the carbon injection process controlled. Also, the operation of a single furnace must be integrated with other furnaces in the melting shop if a rational control of power is to be maintained in these and in the other parts of the plant to reduce the maximum power demand. The furnace, in addition, must be operated to limit the electrical disturbance on the supply line (flicker) which becomes more difficult as the power and number of furnaces are increased.

Electrical energy remains the main cost. Prior to oxy-fuel injection, it required over 500 kWh/tonne to melt a steel charge to about 1600°C. Now with injection the requirement is nearer 440 kWh/tonne.

Electrode consumption is also a significant cost, 2.5 kg is consumed per tonne of output. The graphite loss is due to combustion in the arc or dissolution in the bath if electrodes come into contact with it. Graphite is also lost as the electrode temperature is raised in the furnace. Water sprays from the roof ports to cool the electrode surfaces are occasionally used to limit oxidation.

g) Direct Current EAF

Direct current arc furnaces have now become commercially available. They were developed in Europe but their use spread to Japan and North America in the late 1980s. The advantages of DC over AC operation were appreciated for some time. However, it is only recently that low-cost semi-conductor rectifiers have become available at the high powers needed. Furnaces of over 100 tonne capacity and 90 MVA have been built.

In a DC furnace the arc current flows between an electrode above the metal bath, connected as the cathode and an electrode positioned in the bottom of the furnace and passing through the refractory to make contact with the metal. The maximum power available at present is 75 MVA and 10 kA employing a single 700 mm diameter electrode. Furnaces with up to three top electrodes have been built to overcome this limitation.

The advantages claimed for DC furnaces are:

- reduces electrode consumption by 50%
- 3%–5% reduction in power consumption
- reduces refractory consumption in sidewalls
- reduction in supply disturbance (flicker) by half.

The disadvantages are:

- 50% greater capital cost

- greater refractory wear on furnace bottom
- bottom electrode life.

Bottom electrode design is a key feature and many types are used. These include conductive refractories with a copper external shell and a multi-tin metallic conductor which consists of a manifold with rods passing through the hearth. They are used on medium sized furnaces with currents less than 40 kA. A third type is a single piece metallic conductor made from a large diameter steel plate fitted in the furnace refractory and water cooled where it emerges from the shell.

The electrode is consumed at a rate of about 1 mm/heat. The worn area around it cannot be repaired with gunning mix between heats as the electrode would be covered. Therefore, the life of the bottom is determined by the length of the bottom electrode with up to 1,000 heats being recorded per campaign.

The DC arc furnace operation is in many ways similar to AC except a hot heel practice is common to ensure good electrical contact between the scrap charge and the bottom electrode. With an empty furnace, some light scrap is charged on to the bottom electrode to protect it and to produce a good contact and then a normal charge of scrap added.

Exhibit L Approximate compositions of the main grades of cast iron scrap

Type	TC%	Si%	Mn%	S%	P%
Heavy cast-iron scrap (generally not less than 13 mm thick)	3.0– 3.3	1.6– 2.4	0.5– 2.2	0.10– 0.15	0.5– 1.0
Light/medium cast-iron scrap (generally less than 13 mm thick)	3.1– 3.5	2.2– 2.8	0.5– 0.8	0.10– 0.15	0.7– 1.2
Railway chairs	2.8– 3.5	1.5– 2.5	up to 0.5	up to 0.25	1.0– 1.5
Automotive scrap (motor cylinder blocks, heads, manifolds, crankcases, flywheels)	3.1– 3.4	2.0– 2.4	0.5– 0.8	0.08– 0.14	<0.2
Ingot mould scrap (heavy sections)	3.5– 3.8	1.4– 1.8	0.5– 1.0	0.08	<0.1

Exhibit M Typical compositions of pig irons

Grade	TC%	Si%*	Mn%	S%	P%
Haematite (blast furnace)	3.4–4.5	0.5–4.5	0.7–1.2	0.005– 0.05	0.05 max
Low phosphorus (blast furnace)	3.4–4.5	0.5–4.5	0.7–1.2	0.005– 0.05	0.05– 0.08
High duty pig iron (for ductile iron production)	3.4–4.5	0.5 max	0.1 max	0.005 max	0.03 max

* Silicon content in 0.25% or 0.50% ranges

Exhibit N Carburising materials

Type	Typical approximate range of composition %				
	Carbon	Sulphur	Nitrogen	Ash	Volatile Matter
Graphites (synthetic)	99–100	0.05 max	0.005–0.05	1.0 max	0.0
Petroleum cokes	97–99	0.8–1.8	0.5–0.8	0.5 max	1.0 max
Metallurgical cokes	88–91	0.6–1.2	0.6–1.0	6–10	1.0 max
Sizing grading: coarse 3–9 mm; medium 1–3 mm; fine 0.2–1.0 mm					
Pellets (graphite) 3 x 9 mm					

Exhibit O Alloys for ladle or electric furnace additions

Element	Alloy	Recovery %	
		Charge addition	Trimming addition
Silicon	Ferrosilicon (75% Si) (lump or granular)	90	90
	Silicon carbide (63% Si)	90	-
Manganese	Ferromanganese (75% Mn) (lump or granular)	90–95	90
Chromium	Ferrochromium (60–75% Cr)	90	80–90
	Ni-Cr alloys (60–75% Cr)		
	Cr steel		
Molybdenum	Ferromolybdenum (60–70% Mo)	90	80–85
Nickel	Shot	95	90–95
	Scrap cathode		
	Ni-Cr alloy		
Copper	Scrap		
Phosphorus	Ferrophosphorus (25% P)	Approx 100	85–90
Sulphur	Iron sulphide (20% S)	Approx 100	–
Titanium	Titanium swarf/sheet	–	80

Exhibit P Guide to maintaining quality control in ferrous industries – raw materials for metal production

Raw material	Examples of lack of control	Immediate effect	Effect on casting quality
Pig iron	Required composition not specified on purchase order. Advice note information on chemical composition not used. Batches not segregated and identified in the stockyard. No occasional checking of composition by the laboratory. Batches not used in accordance with composition.	Variable or incorrect metal composition.	Metal not to specification. Metal too hard with chill in free edges Metal too soft. Shrinkage-porosity defects
Cast iron scrap	Return scrap not segregated by grade. Bought scrap not segregated by grade.	Charge compositions not correct.	Metal not to specification.
	Some pieces of scrap too large.	Bridging and uneven melting.	Variable metal temperature and composition.
	Non-ferrous parts containing lead, aluminium, etc, not removed from bought scrap	Contamination of the metal with aluminium.	Pinhole defects.
	Delivery of heavily painted scrap accepted into stockyard.	Contamination of the metal with lead.	Serious loss of strength. Cracking.
	Excess of vitreous enamelled scrap in each charge.	Contamination of the metal with boron.	Chill and increased hardness.
		Contamination of the metal with antimony	Increased hardness.
	Gas works scrap accepted into stock.	Contamination of the metal with high sulphur iron.	Chilled edges and sections. Top surface blowholes.
Steel scrap	Grade and unwanted contaminants not specified on purchase order. Insufficient vigilance to detect and eliminate: <ul style="list-style-type: none"> aluminium 	Contamination of the metal with: <ul style="list-style-type: none"> aluminium 	Pinhole defects.
	<ul style="list-style-type: none"> pieces of sulphur bearing or leaded free cutting steel 	<ul style="list-style-type: none"> sulphur 	Chill and top surface blowholes.
	<ul style="list-style-type: none"> pieces of non ferrous metal in baled/ fragmented scrap, heavily painted scrap 	<ul style="list-style-type: none"> lead 	Serious loss of strength. Cracking.

Raw material	Examples of lack of control	Immediate effect	Effect on casting quality
	<ul style="list-style-type: none"> pieces of stainless steel 	<ul style="list-style-type: none"> chromium 	Chill and increased hardness.
	Pieces larger than $\frac{1}{3}$ cupola diameter.	Bridging and uneven melting.	Variable metal temperature and composition.
Non ferrous alloy scrap	Free cutting copper scrap containing tellurium.	Contamination of the metal with tellurium.	Chilled sections.
	Nickel/copper alloy scrap containing lead and aluminium, and leaded bronze inserts.	Contamination of the metal with lead.	Serious loss of strength or cracking.
		Contamination of the metal with aluminium.	Pinhole defects.
Ferro alloys	Composition and grading requirement not adequately specified on purchase order.	Ferro alloy pieces too large, not dissolved.	Hard spots on machining.
Inoculants Carburisers	Failure to check container labels against advice note information.	Incorrect materials used.	Metal not to specification.
	Materials not clearly labelled or segregated in the stores.	Incorrect materials used.	Metal not to specification.
	Materials not kept dry.	Moisture pick-up.	Pinhole defects.
	No laboratory checking of materials against specification, eg aluminium or ferrosilicon.	Aluminium contamination.	Pinhole defects.
	Variations in sulphur and nitrogen in contents of carburisers.	Variable content of sulphur and variation in response to inoculation treatment.	Chill or poor graphite structures.
		Variable content of nitrogen.	Fissure defects. Variation in tensile strength and hardness.
Coke	No action taken to avoid the use of small coke, i.e. below a mean size of 9 cm	Reduced melting rate and lower metal temperature, unless blast increased.	Top surface blowholes.
	No periodic laboratory checking for quality, eg sulphur and ash contents.	Sulphur and carbon pick-up vary.	Top surface blowholes.

Exhibit Q Schematic outline of a cupola furnace

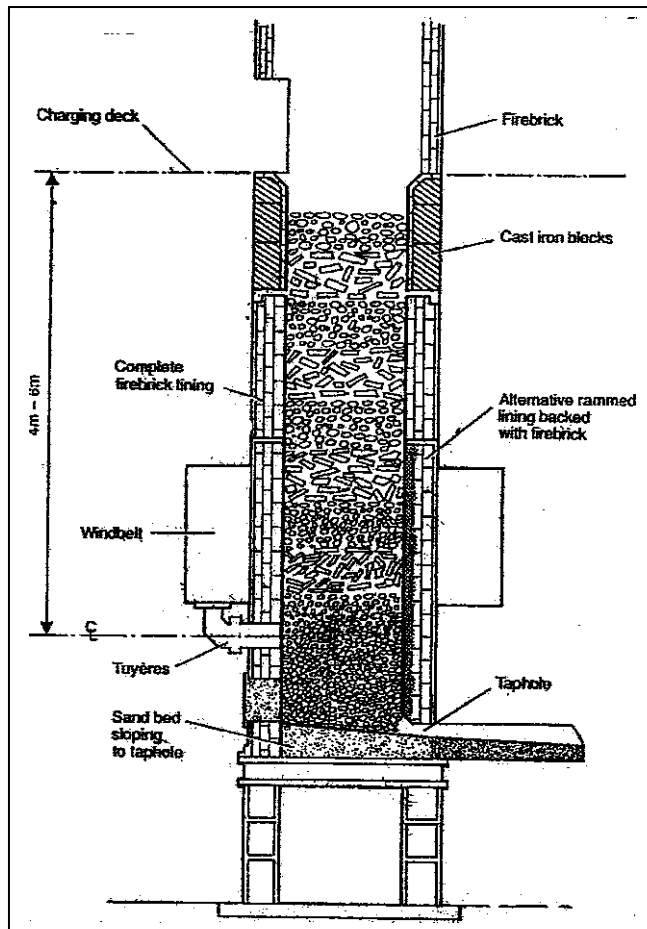


Exhibit R Divided blast cupola

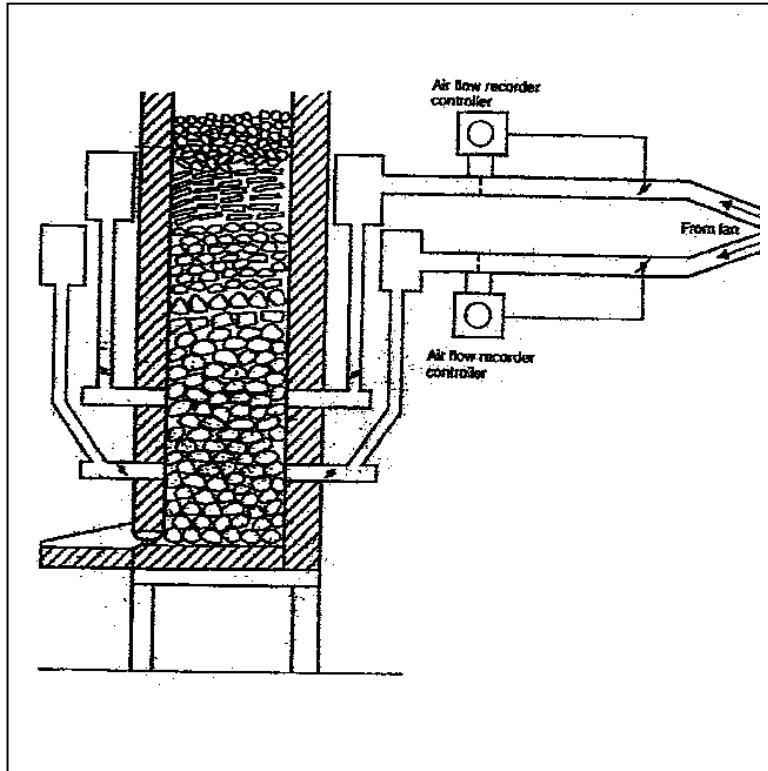


Exhibit S How metal temperature can be increased or how coke consumption may be reduced and melting rate increased by divided blast operation

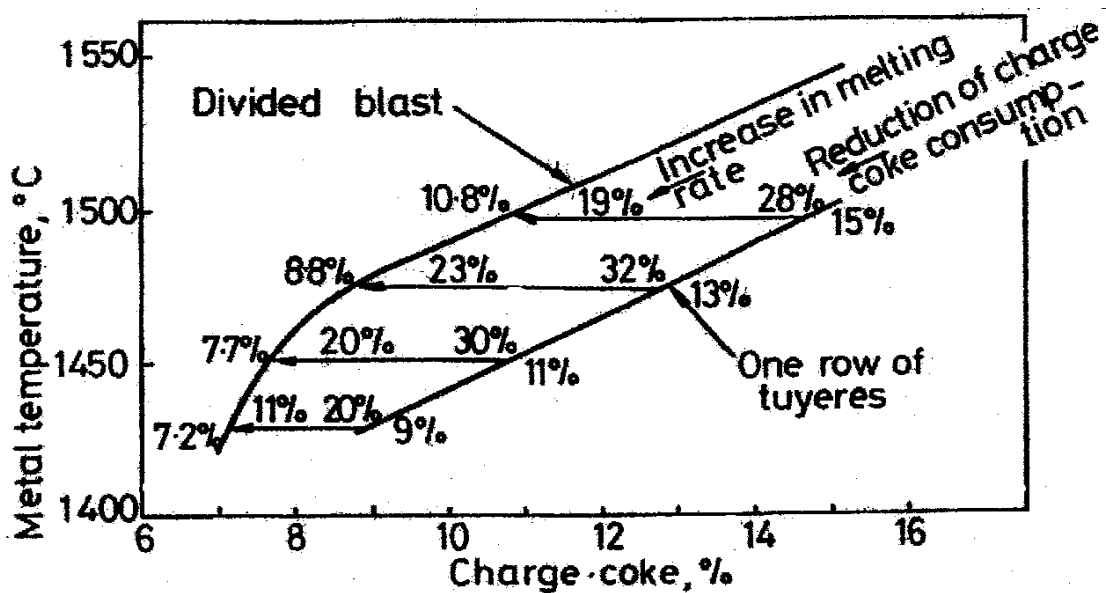


Exhibit T Coreless induction furnace

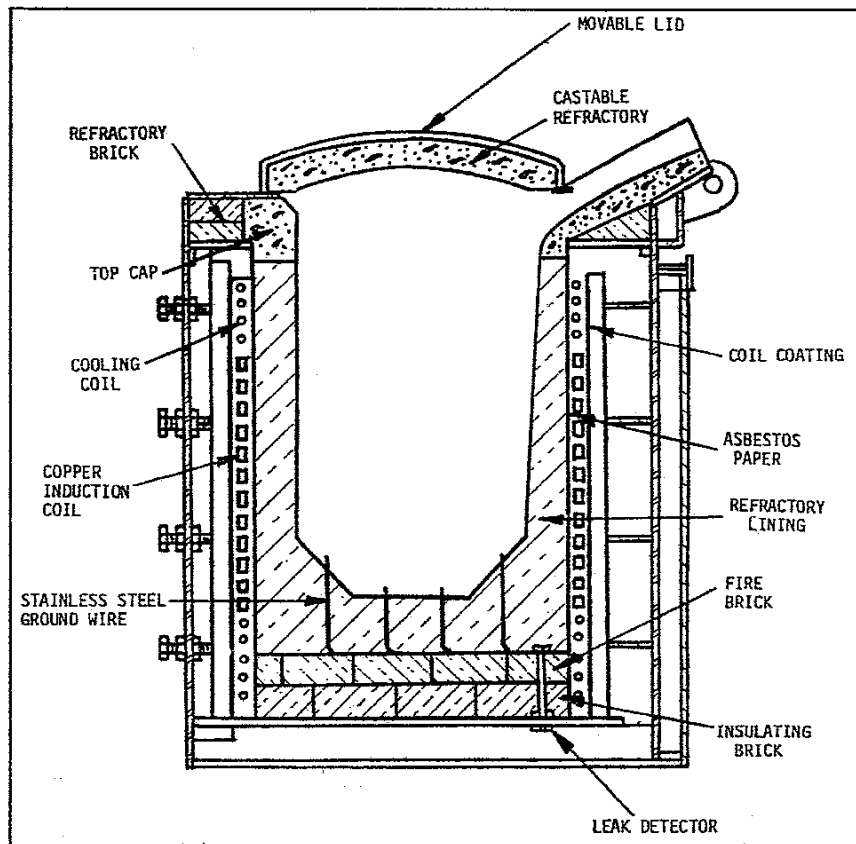


Exhibit U Stirring action

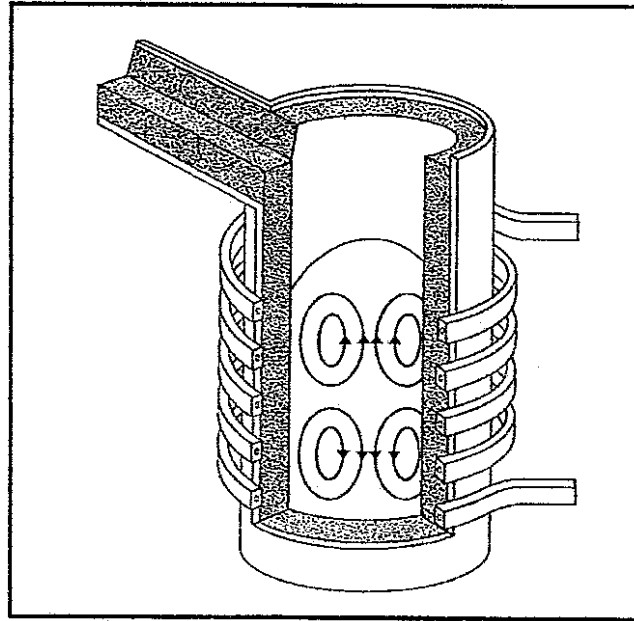


Exhibit V Vertical channel furnace

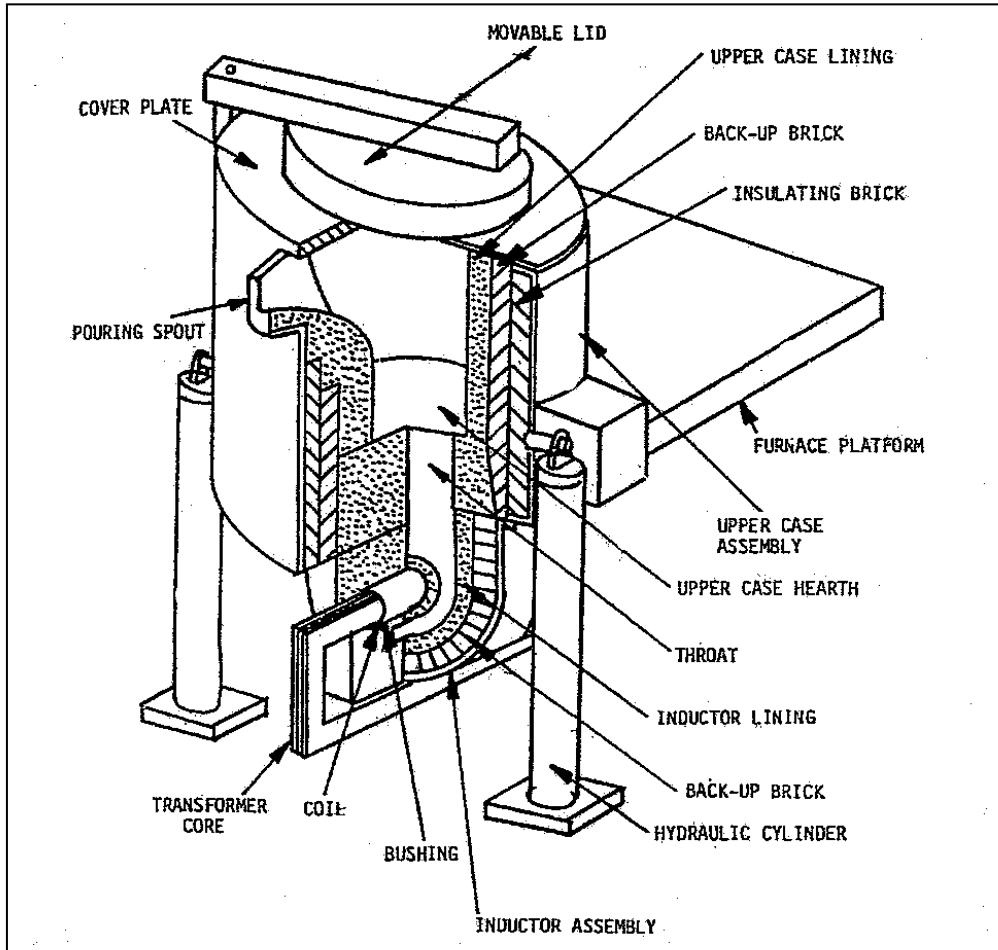


Exhibit W Drum type channel furnace

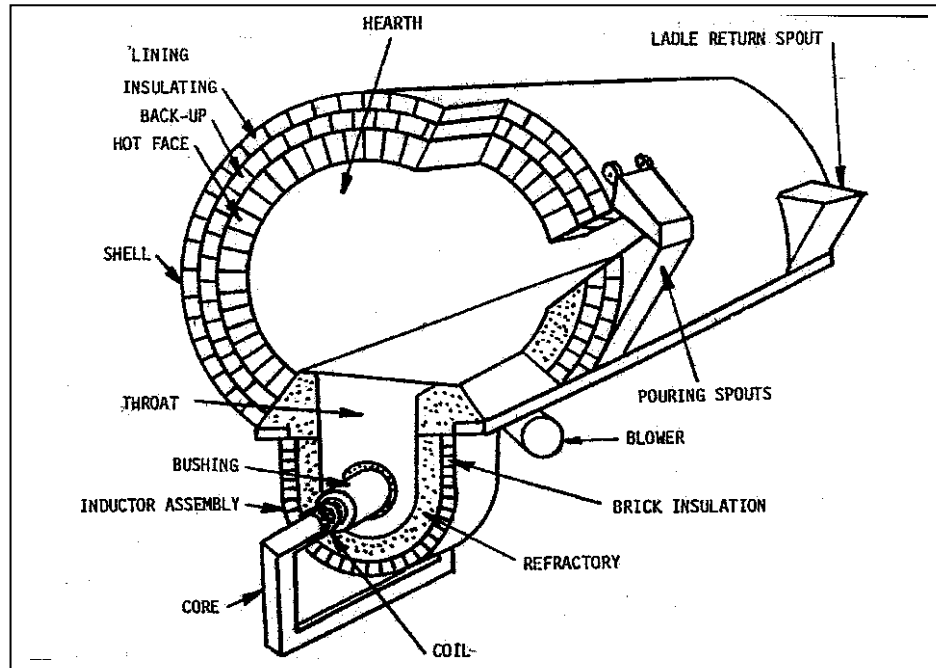


Exhibit X Examples of the electrical currents carried by electrodes at nominal installed furnace power

Furnace Capacity Tonnes	Nominal installed power MVA	Maximum secondary voltage Volts	Maximum secondary current kA
40	36	560	50
100	65	800	58
400	103	900	80

4.0 METAL TREATMENT AND POURING

4.1 Inoculation

a) Grey Cast Iron

Although grey cast irons are brittle materials and fail in tension with negligible elongation, their other mechanical and physical properties, and the ability of the foundryman to control these properties, results in a wide range of suitable applications. Flake graphite grey irons with strengths in the range 100–450 N/mm² have the widest applications in general engineering. The properties quoted in specifications are on the basis of 30 mm cast bars. The materials have low impact values. The strength is controlled by the form of the graphite and by the matrix structure which can be adjusted by the foundryman. Inoculation is required to produce the appropriate flake size, whereas small amounts of alloying elements can alter the matrix.

The purpose of the inoculant is to increase the eutectic cell count, produce good quality randomly-orientated graphite flakes and to prevent under-cooling. Most inoculation is carried out by the addition of ferro-silicon. However, the ferro-silicon is normally only the carrier for the active elements which are normally anti-oxidants such as aluminium, calcium, strontium, lanthanum and many rare earths. The use of aluminium must be carefully controlled as hydrogen pin-hole defects can result.

Addition rates of inoculants vary from 0.05–0.5% depending on the casting section size, the carbon equivalent and the physical properties required. It is important that inoculation should be carried out as late as possible.

b) Ductile Iron

Additions of magnesium to the molten iron produce graphite in the form of nodules rather than flakes. The nodular graphite morphology has a lower weakening effect than the flake graphite and as a ductile iron (or nodular iron or spheroidal graphite iron) exhibits higher strength and ductility properties.

Ductile iron combines good foundry characteristics with good engineering properties, thereby widening the range of applications for the iron founder.

Although not so section-sensitive as grey iron, the inoculation of nodular iron necessitates a higher level of process control.

Inoculation involves the addition of magnesium based nodularising material followed by a ferro-silicon addition to increase the nodule count.

The nodularising of the iron can be carried out by several different processes:

- ferro-silicon by sandwich or tundish
- wire treatment process
- GF converter
- in-mould treatment.

Generally speaking the higher the magnesium content of the nodularising material, the more efficient and effective is the treatment process.

After nodularisation the material has to be inoculated in order to increase the number of nodules and improve their distribution. Several materials that are used to inoculate grey irons are not effective when used for ductile iron. Cerium and other rare earths are the most effective materials.

All properties relating to the strength and ductility of nodular iron decrease as the proportion of non-nodular graphite increases.

Ductile (or spheroidal graphite) cast irons have a range of properties largely controlled by the matrix which can range from completely ferritic to pearlitic (as-cast or normalised). Pearlitic structures are promoted by additions of Cu and/or Sn. Pearlitic grades are characterised by high strength and relatively low ductility and impact. Ferritic irons show lower tensile strength but good impact properties.

Ductile iron is used for many structural applications requiring strength and toughness. Typical applications include gears, crankshafts, disc brake callipers, steering knuckles, railway components, textile machinery, spun pipes and machine tools.

4.2 Secondary Steelmaking Processes

Due to market demands for cleaner steel castings with better properties, the prime melting furnace has often become a source of bulk liquid metal and secondary refining of the steel takes place. The main reasons to use secondary techniques are for alloying control to improve steel cleanliness and to enhance mechanical properties. Low sulphur requirements, for example in pressure vessels, will ensure the growth of secondary steelmaking, as the very low sulphurs required are difficult to achieve in induction furnaces.

An illustration showing many of the secondary metallurgical methods is shown in Exhibit Y. The main methods currently used in the steel foundry industry are AOD and ladle vacuum units (as typified by the DETEM process).

a) Converter Processes

Metal from the prime melting furnace can be transferred to a converter for further treatment, including degassing of the steel.

The most common process currently in use is argon-oxygen decarburisation (AOD), a patented process that has gained world-wide acceptance for producing stainless and other high alloy cast steels. AOD uses commercial high-purity argon and nitrogen, as well as oxygen. The gases are injected into the metal through side-mounted tuyeres. Steelmaking by AOD is a duplex process. Meltdown in an electric arc furnace is followed by refining in the separate AOD vessel (converter). In commercial steel foundries, carbon and low alloy components, as well as stainless steel parts, now are processed through AOD vessels. Through judicious metallurgical manipulation, decarburisation progresses with minimal chromium oxidation when stainless steel heats are processed. A high degree of contact between slag, metal and gas is critical, however, for effective pyrometallurgical reactions.

The most important aspect of AOD is the reduction of the partial pressure of CO by argon, allowing carbon removal in the presence of large chromium concentrations.

Variations of this process involve the use of vacuum or inert gases such as nitrogen, with oxygen injected to reduce carbon.

b) Ladle Metallurgy

Several improved and new processes collectively are called 'ladle metallurgy' since they are carried out increasingly in a ladle type vessel. The ladle no longer is used exclusively to transfer metal from furnace to mould.

It also can carry out a variety of refining steps as part of the overall melting operation. Part of the incentive to develop these auxiliary practices has been the need for cleaner metal with lower oxygen and sulphur content and the desire for inclusion shape control and inclusion reduction.

Proper ladle practice can accomplish the following with predictable success:

- more efficient alloy addition and control of final chemistry
- improved deoxidation and desulphurisation
- high degree of inclusion flotation
- improved temperature and composition homogenisation
- sulphide and oxide shape control.

The ladle furnace has a roof that can be swung over and carries normal AC graphite electrodes for heating the metal. Normally, only corrections of analysis are carried out in the ladle furnace. In special cases, large quantities of alloying agents can be added, but this increases both treatment time and electrical consumption.

Many steel foundries have employed some form of calcium (Ca) treatment to help minimise reoxidation – a concept borrowed from steel mills. Calcium is the strongest deoxidiser used in steelmaking. When added to steel, it chemically combines with oxygen in solution and in non-metallic inclusions within liquid steel.

The most efficient method of introducing calcium is feeding steel clad calcium wire through the slag cover and deep into the molten steel beneath, where it melts quickly. To further ensure a good recovery, it has been found that keeping a tight fit cover on the ladle during and after injection keeps the element from dissipating. As a liquid at steel temperatures, calcium has the following effect:

- modifies alumina clusters into small globular calcium alumina silicates
- transforms high-melting point alumina silicates into low-melting point calcium aluminates which give better fluidity
- allows pouring temperatures to be reduced up to 40°C, saving energy
- improves metal flow, allowing a tighter pouring stream with less surface to reoxidise
- modifies hard alumina particles into soft calcium alumina silicates for easier machining
- improves mechanical properties, especially toughness, at low temperatures.

An optimum balance between calcium and alumina has to be struck, with the correct ratio of Al:calcium being 1:0.12.

Calcium wire injection has proved to be one of the most effective ways to reduce oxide macro-inclusions in steel castings. Many foundries report an average of 40% reduction in defects.

To try and protect the metal from oxygen many foundries have employed argon gas to insulate the steel. Argon, which is heavier than air, creates a layer of controlled atmosphere between the steel and the ambient air, limiting reoxidation from that source.

One beneficial use has been to blanket the surface of the metal in the ladle with argon. This can be accomplished by adding argon directly to the steel via porous plugs at the bottom of the ladle, where it will evaporate into the atmosphere directly above the bath.

Argon by its stirring action through the steel will:

- homogenise the metal composition
- equalise temperatures
- float deoxidation products
- achieve some degassing.

c) Induction Heated Methods

Secondary steelmaking can also take place within special ladles that are placed into an induction heating coil to maintain temperature when alloying and vacuum treatment takes place. The ladles have to be manufactured from special steel to allow transference of the power through the ladle and into the metal. This is likely to be an area of growth in the future.

Another method for very high integrity castings for the aircraft industry is to use a vacuum induction degassing and pouring (VIDP) furnace. The VIDP furnace has a crucible body which is vacuum tight, rather than using a vacuum chamber to surround the crucible. Gas is bubbled through the melt via a porous plug in the bottom of the crucible. During pouring, the furnace body, coil and crucible all tilt and the metal transferred via a pre-heated ceramic launder to the casting station.

4.3 Pouring

a) Grey and Ductile Iron

There are three main ways available for the pouring of grey and ductile irons:

- Manual pouring using a lip pour or teapot spout ladle.
- Mechanised or automated ladle pouring.

Such systems can be synchronised to the movement of a moulding line and, if required, can dispense calculated amounts of metal, varying according to the requirements of individual box weights.

- Press-pour or autopour furnaces.

Such systems dispense metal into the mould automatically within the moulding line cycle-time. The volume of metal dispensed can be controlled by a laser-pour system and inoculation of the iron is carried out automatically by powder injection during pouring. These vessels can be heated or unheated according to the alloy requirements.

b) Steel Alloys

Good ladle practice is essential to make good steel castings. For castables and brick, thorough pre-heating to 800°C should be followed by rapid transfer from the melting furnace or secondary steelmaking unit. Ladles lined with insulating board are not pre-heated, but the stopper rod assembly and high quality nozzles should be pre-heated in a special oven.

Ladles should be pre-heated with ladle heaters designed with energy saving in mind, not burners thrust into ladles without covers.

When the metal is tipped into the ladle, if pouring time is likely to be extended by casting a number of moulds, the metal should be covered by an insulating material. Minimum holding and super heating of metal should take place by having moulds ready to be poured when the metal is ready.

There are two important impurity sources that influence casting cleanliness. One is the entrapment of slags, refractories and moulding sand, which can be minimised through careful adjustment of foundry practices. Studies have shown, however, that 83% of inclusions are the result of reoxidation – the reaction of deoxidisers in the steel with oxygen. It is standard practice for foundries to deoxidise the steel with the addition of aluminium. Deoxidation particles generally measure about 5 microns. Particles of 10+ microns are termed macro-inclusions.

Reoxidation is a local condition within the melt in which reintroduced oxygen combines with and swells the aluminium particles to form large inclusions. It can be caused by exposure of the steel to air, poor refractories, slags high in ferrous oxide, or mould binders with a high oxygen content.

To minimise reoxidation during pouring, several methods of argon protection have been tried. One is to shroud the pouring stream in argon, but unfortunately no truly efficient method of shrouding has yet been found for production use.

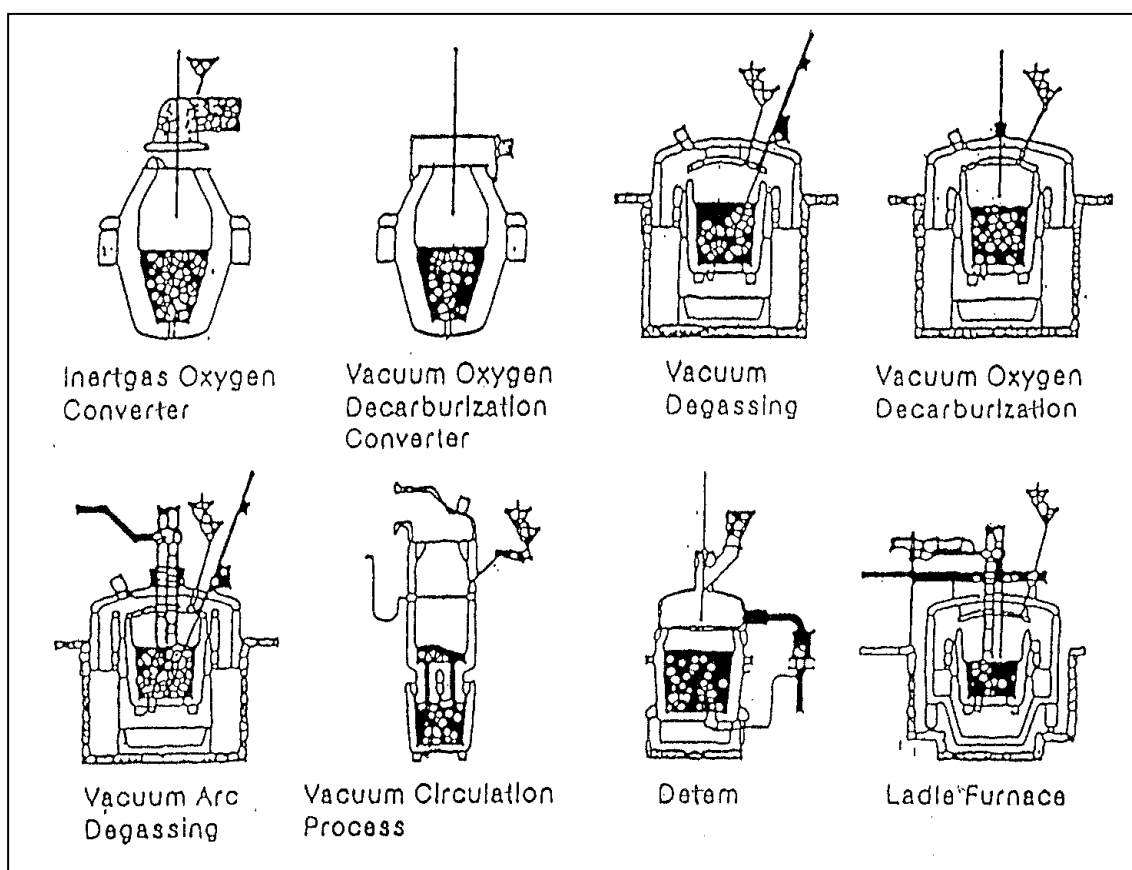
Three types of ladles are commonly used in steel foundries:

- The bottom pour ladle has an opening in the bottom fitted with a refractory nozzle. A stopper rod suspended inside the ladle pulls the stopper head up from its seat in the nozzle, allowing molten steel to flow from the ladle. When the stopper head is returned to the seated position, the flow cuts off. Care must be taken if trying to make castings less than 50 kg in weight using bottom pour ladles.
- The teapot ladle incorporates a ceramic wall or baffle that separates the bowl of the ladle from the spout. The baffle extends almost 80% of the distance to the bottom of the ladle. As the ladle tips, hot metal flows from the bottom of the ladle, up the

spout and over the lip. Since the metal is taken from near the bottom of the ladle, it is free of slag and pieces of eroded refractory, although it may pick up foreign materials in the spout section or at the lip. Teapot design ladles are possible that cover the range of castings sizes up to 100 kg, smaller than those for which bottom pour ladles are used.

- Lip pour ladles are similar externally to the teapot type. Because lip-pour ladles have no baffles to hold back slag, this type is rarely used in the steel foundry except as a transfer ladle.

Exhibit Y Secondary metallurgical process methods



5.0 MOULDING

5.1 Moulding Process Options

There are a wide range of moulding processes available and the major ones are illustrated in Exhibit Z.

The choice between the different moulding methods depends on the following principal factors:

- The volume of castings required per annum.
- The product types to be made.
- The size (weight) of castings to be produced.
- The dimensional tolerances that have to be maintained – Exhibit AA shows a comparison of the dimensional tolerances that can be achieved by various moulding processes.
- The surface finish that is specified by the customer. This is illustrated for a number of processes in Exhibit AB.
- Other more subjective factors such as tool costs, complexity of design, ease of engineering changes and near net shape capability. These factors are described for various moulding processes in Exhibits AC to AF.
- Manufacturing costs versus achievable sales value.

Only the major processes in use will be discussed. These are:

- greensand – both flaskless and conventional flaked
- chemically bonded – both cold and heat set
- physical – lost foam and V-process
- permanent mould – centrifugal, as static is for a limited market.

5.2 Sand Properties

a) Introduction

Almost all steel and iron castings and a large proportion of non-ferrous castings are made by a sand moulding process. It is one of the most important technologies to understand for the production of sound castings with good surface finish.

b) Sand Properties

(I) Sands

Foundries employ a wide variety of moulding and coremaking processes which have a number of different technical requirements. The main one is the use of a refractory material of a high quality; the most suitable material which matches the particular

demand. These are normally of the silica type although zircon, chromite or olivine sands are used.

There are a number of different types of sand employed in normal foundry operations, each providing some specific benefit to the moulding or coremaking process selected. These include improved economics, higher thermal refractoriness, low thermal expansion or reduced mould-metal reactions during casting.

The majority of sands used by Western European foundries are of high silica type which are extracted from deposits from many areas, and their properties are dependent on the geological origin. For example, sands from estuarine deposits generally have a well rounded grain, sands from glacial deposits have a sub-angular to rounded grain shape and crushed sandstones produce angular grains. Some deposits are associated with significant quantities of clay and these sands which often have a fine grading are known as naturally bonded sands, but are not suitable for use in synthetic sands or for use with any of the chemical binder systems.

Non-siliceous sands such as zircon, chromite and olivine are used, although the tonnages are relatively small owing to limited supply from foreign sources (eg zircon from Australia) and their consequent high prices.

There are several basic properties of a sand which markedly affect its performance with the various binder systems. These include the following:

Grain Size and Distribution

The grain size of sands is a major factor in determining mould/core permeability and casting surface finish. For most purposes sands with average grain sizes in the range 200–300 microns (AFS Fineness No 75-50) are suitable. Fine sands of less than 200 microns (AFS Fineness No 75) are often used for greensand moulding for non-ferrous and grey iron castings and shell moulding where a very fine casting surface finish is required. Coarser sands (>300 microns) would be used especially in coremaking where very high gas permeability is required to prevent such defects as gas holes, blows, etc.

It is generally believed that the best size distribution within a sand is one with a reasonable amount of grains spread over four or five adjacent sieves. This appears to give the highest strengths on compaction and maximises resistance to expansion defects. Hexagonal close packed structures with finer particles filling the interstices or voids between coarser particles gives maximum compaction/density and minimum permeability. However, increasing the spread of the grain size distribution of the sand, particularly where +500 micron sand is included, may lead to segregation of the sand with undesirable effects on casting surface finish.

Grain Shape

Sand grains can vary in shape from angular through sub-angular to rounded. Angular sands have a low packing density and a high surface area and therefore require significantly more binder and catalyst to give adequate mould/core strength. This is more costly and may lead to higher gas evolution with possible gas defects or blowholes in castings. Sub-angular to rounded grains are satisfactory as they offer a compromise between the problems associated with angular sands and the thermal expansion defects which can occur with a well rounded sand on account of its high packing density. Most of the clean, reasonably pure silica sands available to the foundry industry in Western Europe are sub-angular to rounded and will give high strength moulds/cores of good quality.

The angularity of a sand can be estimated by visual examination with a low power microscope.

Exhibit AG illustrates the principal grain shapes commonly used to describe foundry sands.

Grain Surface Porosity

The effect of porous surfaces and particles in the sand would be to increase binder/catalyst requirement. Surface porosity is rarely a basic sand problem.

Chemical Composition

Silica sand principally consists of the mineral quartz (SG 2.6) which is a good refractory material up to 1650°C. Sands of high silica content are essential to obtain good refractory properties of moulding or coresand mixtures. This is especially important for steel and high temperature iron castings.

Burn-on problems can occur if sands contain more than 0.5% potassium or sodium oxides (usually as feldspar and micas) in particles greater than about 0.1 mm. Calcium and magnesium oxide should not exceed about 1%. Sea sands which often contain shell can also be troublesome, as the calcium carbonate breaks down above 800°C to release calcium oxide which can reduce refractoriness.

Exhibit AH contains a table which shows the effects of impurities on sintering points of sands which are an indicator of the refractoriness of the sand.

Low sintering point sands are normally associated with the occurrence of poor surface finish for iron and steel castings.

Zircon sand is based on zirconium silicate ($\text{ZrO}_2 \cdot \text{SiO}_2$) with a specific gravity of 4.7. It occurs in Australia (New South Wales), South Africa and Florida and is the most widely used of the non-siliceous minerals in the foundry, principally because of its very high refractoriness and low thermal expansion. It is compatible with all binder systems and low levels of binder can be used to obtain high bond strength. Zircon has a chilling capacity and this may limit its value in some applications.

There are some supplies of zircon on the world market which contain significant quantities of radioactive minerals. There is no information at present of the extent of any risk to health of these sands, but foundries should be aware of the possibility and purchase supplies of satisfactory sands from reputable companies.

Chromite sand is composed mainly of chrome iron spinel (SG 4.5) which is a combination of the oxides Cr_2O_3 , Fe_2O_3 and Al_2O_3 . Its properties are similar to those of zircon, but it is a little less compatible with some of the resin binder systems. Some difficulty may be experienced with acid catalysed cold-set processes, for which extra catalyst could be necessary to maintain curing times. The major producer of chromite sand is South Africa.

Olivine sand is based on magnesium iron orthosilicate and has a specific gravity of 3.3. Supplies come mainly from Norway and may contain significant amounts of hydrated minerals and carbonates which decompose in the range 500–900°C. Like zircon and chromite, it has a low uniform thermal expansion, but it is not compatible with resin binders which rely on acid catalysis processes for curing. Olivine sands tend to accelerate the curing of phenolic urethane binders. Their main use is in the production of manganese steel castings.

(ii) Acid Demand

The chemical composition of the sand, as it affects the acid demand, has an important influence on the catalyst requirements of cold-setting acid-catalysed binders and sands containing alkaline minerals or sea shell can absorb a considerable amount of catalyst.

(iii) Clay Content

Clay contamination of silica sands for use with chemical binders can be a nuisance, leading to inefficient use of resin and catalyst with substantial increases in costs. Clay content should preferably be below 0.3% and certainly no higher than about 0.5%. To

ensure a low enough clay content the sand should not contain more than 0.5% of particles less than 20 microns.

(iv) Moisture Content

This is not a fixed quantity for sand, it is more closely related to the supplier's practice, delivery arrangements and storage conditions at the foundry. Some resin binder systems and clay bonded sands can tolerate a moderate level of moisture in sands prior to mixing, but some, notably urethane based binders, are especially sensitive to moisture and dry sands are essential for adequate performance.

5.3 Clay Bonded Processes

a) Greensand

Base Sand Selection

This topic is more important than the technical staff of foundries often realise, and is essential to ensure that the basics are correct, otherwise casting problems can occur.

The selection of a sand to be used in a greensand is dependent upon such factors as casting design, metal to be cast, pouring temperature and the cosmetic finish required.

Sands are categorised by grain shape (i.e. rounded, sub-angular or angular – see Exhibit AG).

A round grained sand gives higher green strengths, better flowability and good permeability, due to more regular and even distribution of the bonding agents.

A sub-angular, semi-rounded sand grain is more common. Angular and compounded grains are more difficult to control and are often only used for cost savings.

In Western Europe the silica sands available are generally of the sub-angular to rounded type, and give reasonable results in iron and steel foundry practice. However, in specific cases it may be necessary to use a very round grained fine sand such as Zircon, in order to give an excellent finish plus chilling characteristics. Larger castings could use chromite sand particularly for its chilling properties rather than the cosmetic finish obtained. Olivine sand is used specifically for manganese steel production.

The grain shape and size of all these sands must be taken into consideration, along with their thermal expansion and thermal conductivity characteristics. These factors will determine the correct additions to be made to the greensand to produce good results.

To obtain these criteria, most Western European foundry sand suppliers wash, screen and dry the silica sand in order to deliver it to foundries with an acceptable sieve grading, generally AFS fineness number 45–90, which gives the foundries a good starting point.

For greensand production a good base sand with a four sieve spread, gives far better results than one which has a widely dispersed grading, or peaks on one or two sieves.

A major priority, often overlooked in many foundries, is that new sand must be added on a continuous basis to the return sand in the ratio of 10 to 15% of the weight of metal poured, or 2 to 3% of sand mixed. Far too often foundries consider that the sand returned via cores is sufficient, and experience has proved that this can create extensive problems. Core sands of a specific grain size and shape can alter the greensand grading

substantially over a period of time, leading to a close packed hexagonal structure, which can result in expansion defects.

b) Clay Binders

There are various clays available world-wide, many having been tried for foundry application, but the three basic types generally in use are Kaolinites (fire clay), Montmorillonites (bentonites) and Illite.

Montmorillonite is the major clay mineral of bentonite, a three layer sheet structure composed of two layers of silicon-oxygen tetrahedrons and one central dioctahedral or trioctahedral aluminium – hydroxyl layer (Gibbsite). This central aluminium layer is made up of octahedrons having an aluminium atom surrounded by 6 hydroxyl units (Al) (OH).

See Exhibits AI and AJ.

Sodium clays, calcium clays and ‘ion exchange’ bentonites fall into this category and are the ones used most extensively in the industry.

Kaolinite has a two layer structure with one aluminium octahedral layer and one silica tetrahedral layer. The silica layer is composed of 1 silicon and 4 oxygen atoms. The second layer (Gibbsite) is composed of 1 aluminium atom and 6 hydroxyl ions. See Exhibit AK.

Fire clays, china clays, kaolins and ball clays fall into this category. These are used very little in modern foundry practice, the main application remaining in dry sand practice for steel casting.

Illite is a low refractory clay. It is the predominant constituent clay found in most naturally bonded sands, but is never isolated and used as a basic clay material addition.

Montmorillonite, having the central aluminium hydroxyl sheet in the sandwich between the two silicon oxygen layers is never totally pure aluminium hydroxide. Part of the aluminium is always replaced by divalent magnesium, creating an ionic imbalance which requires balancing. Balancing may be achieved with sodium/calcium or magnesium, known as an ‘exchange ion’.

In modern foundry practice many clays used in foundries are of the ‘ion exchange’ variety.

The two major Montmorillonites used in foundry applications are:

- sodium bentonite, characterised by high swelling properties
- calcium bentonite, which is non-swelling and absorbs less water.

'Ion exchange' bentonites are calcium bentonites treated with sodium salts, i.e. sodium carbonate (soda ash), to improve the characteristics of the clay. This activation increases wet tensile and liquid limit figures to give improved durability and anti-expansion defect properties without the particular disadvantage of high dry strength. This activation can be 'dry' or 'wet', but results indicate that wet activation is superior.

Sodium bentonites, calcium bentonites and 'ion-exchange' clays each exhibit unique properties. Choosing the correct clay or blend will be dependent on process requirements and economic justification on a foundry to foundry basis.

It will generally be found in greensand practice that sodium bentonite (Wyoming), is used for steel casting production, calcium or 'ion-exchange' bentonite or a blend of sodium/calcium clay is used in iron and non-ferrous application.

Each foundry should know its own requirements and select its clays accordingly. A clay or blend can be developed to suit most requirements. This is particularly important with the advent of high pressure moulding and the demands placed upon the performance of greensand additives.

c) Other Additives

Over the years many alternative additives have been tried to improve the performance of greensand but the major ones currently in use are listed below:

- coaldust
- coaldust replacements
- starches, cereals, dextrans
- woodflour
- iron oxide

(I) Coaldust

This is used primarily in iron casting production with some application to non-ferrous work. Coaldust improves casting strip and to some degree casting finish. It helps control expansion defects due to its burn-out characteristics, particularly on the mould face. Volatiles given off during casting produce lustrous carbon which improves casting strip.

On casting, coaldust burns, and oxygen to support combustion is drawn from the mould cavity, producing a reducing atmosphere within the mould cavity.

As the temperature increases, the coaldust 'cokes' producing uncondensable reducing gases, such as hydrogen and methane. The tars and oils burn producing a carbon film.

This 'sooting' helps prevent metal penetration into the sand grains and forms a cushion which allows the metal to lie quietly on the mould surface. The burnt-out coaldust at the mould/metal interface increases permeability assisting the escape of gases and helps to compensate for surface sand expansion preventing rat tails, scabbing, etc.

(ii) Coaldust Replacements

These have been developed over the last 20 years and normally consist of a blend of high volatile/high lustrous carbon producing base material, blended with coaldust and clay.

Originally, coaldust was not used, but it was found that control limits required were very restrictive, and in most cases coaldust was introduced to provide greater flexibility, particularly with regard to moisture control and the requirement for an extended reducing atmosphere for SG iron.

Coaldust replacements have been accepted in Western European foundries as a match for coaldust. They are generally more economical and particularly more environmentally acceptable, due to less fume evolution on casting. They can be tailored to suit particular applications particularly with regard to high pressure moulding, and also for the production of ductile iron, where the sulphur content is reduced substantially, helping to prevent the edge flake defect.

(iii) Starches, Cereals and Dextrines

These are used mainly in steel casting production, but occasionally in iron for specific applications.

Cereals tend to increase green strength, dry strength and sand toughness, but can reduce flowability. More water may be required to be added to the sand mix, with the attendant potential for moisture related defects.

Dextrines promote better flowability and plasticity.

They help with moisture retention and are particularly useful in preventing moulds drying out and edges becoming friable.

Starches produce a reducing atmosphere similar to coaldust in iron casting. As it is a volatile carbohydrate, it uses oxygen from the mould cavity.

As the temperature increases, starches burn out to accommodate sand expansion, helping the prevention of expansion defects. This is the area where foundries feel they are obtaining the greatest benefit.

(iv) Woodflour

A very fine soft woodflour used predominantly in iron casting production, as steel foundries tend to use a starch-based additive, but it is claimed that woodflour is similar to the starches in that it produces a reducing atmosphere although to a lesser extent, and on burn-out gives good resistance to expansion defects. However, woodflour tends to lower dry strength and if care is not taken friability of moulds can occur. Too high a moisture level makes the sand spongy, difficult to ram and susceptible to moisture related defects.

In malleable iron production it is particularly useful, giving good collapsibility with lower hot strength, thereby helping to prevent expansion defects. On moulding, it decreases density, improves flowability and accepts water readily giving a much more flexible moisture band. It does not feel 'sticky' as the starches tend to.

It is often used with naturally bonded sand, to overcome expansion defects, particularly on flat surfaces and also helps to improve casting strip. In some instances it can be substituted for a percentage of the cereal or starch addition.

Environmentally undesirable, due to the amount of smoke generated on casting.

(v) Iron Oxide

Used primarily to overcome finning and veining. It improves hot plastic deformation and increases hot strength. Although it is sometimes used in greensand in small amounts, its predominant use is with hot box resins, shell, dry sand and phenolic urethanes.

d) Water

Although water quality may seem of little importance, due to the increase in the recent past of chemically bonded sands, which break down and enter the return sand system, it has been proved that some of the chlorides and sulphates produced from return material, plus those contained in mains supply water at certain levels of concentration, can have a detrimental effect on the clay binder, causing lack of bond development, friability and premature break down of the sand and a demand for increased clay additions.

A number of foundries are already using de-ionised water additions to overcome this problem. Breakdown products from some modern core binder materials contaminate return moulding sand and may increase water requirements for control of the system.

e) Mixing/Mulling

The requirement is to develop correct properties to produce good sand moulds and good castings.

Sand mulling must be thorough. Too many foundries do not mull long enough, often due to production requirements and thereby lose consistency.

Hot return sand requires more mulling and higher moisture additions to compensate for evaporation cooling.

Short mulling time produces brittle sand, with low green strength, under-mixed additives and, most importantly, variable moulding properties and lack of control.

Therefore, optimum mulling cycles must be established and adhered to in all foundries and particular attention must be given to manufacturers' instructions and maintenance.

The use of aerators immediately prior to the moulding machine hopper or the moulding machine itself, produces improved flowability and mouldability (equivalent to 'riddling' the sand) and often helps to partially overcome shortcomings in the mulling operation.

f) Mixing Equipment

(i) Mills – Counter Current Intensive Mixers

Batch Mixing

This type of mixer, which can process sand in batches of a few kilograms up to seven tonnes, employs counter flowing currents of material in order to achieve an homogeneous mix of sand, clay and water in a relatively short time.

The design of mill varies slightly with each manufacturer. Some manufacturers use a rotating pan which transports the sand into the path of a high energy rotor that is rotating against the flow of the sand. Other manufacturers have a stationary pan and rely on ploughs rotating on the pan floor to move the sand into the path of the mixing blades.

A moisture probe is either resident in the mixing area or may descend into the mix and via a PLC (programmable logic controller) controls the quantity of water addition.

At the end of the allotted mixing time when maximum strength has been achieved, the sand is discharged from the mill, usually through a door in the pan floor.

To avoid internal build-up these mixers are fitted with a scraper unit that removes the sand and returns it to the centre of the unit.

Additions to the mix, such as clays, water, coaldust, etc, are added either manually through openings in the top of the mill, or more usually they are introduced from hoppers above the mill.

A PLC controls water requirements utilising a probe in the mixing zone.

Continuous Mixers

The internal design of the continuous mixer is essentially the same as the batch type, apart from the size of the exit door. The large exit door used in batch production is reduced to about 25% of the former size and may incorporate a cone section, which helps in regulating the quantity of sand passing through the discharge opening.

The actual quantity of sand being discharged is controlled by the current drawn by the mill motor. As the disc feeder is driven by a DC motor, the speed of rotation adjusts the condition of the mixed sand. When the current rises towards the pre-set limit, the disc feeder speeds up. Conversely, if the sand has not yet reached its full blended strength, the feeder slows to allow more time in the pan.

(ii) Mills - Mullers

Batch Mixing

The early batch type mullers employed vertically set heavy wheels and large ploughs to distribute the sand mass – Exhibit AL. This design of mixer, although capable of producing good quality mixed sand, is not capable of supplying large volumes and is restricted to around 30 tonnes per hour.

Modern batch mullers, often called speed mullers, incorporate multiple rubber tyred wheels which are set horizontally – Exhibit AM. Multiple ploughs are also used to increase the throughput.

Continuous Mixers

For larger volumes of mixed sand the continuous mixer is used – Exhibit AN. Its control is similar in operation to that of the intensive mixer in that the discharge door is opened only when the current on the main drive motor reaches a pre-set limit.

Comparison of Counter Current Intensive Versus Conventional Muller

Although conventional mulling still has many adherents, the majority of high production foundries built today use the intensive mixing principle. Tests carried out some years ago but which are still valid today compared mulling to intensive mixing in the following areas of operation:

- bulk density against time
- energy input against time (mixing intensity).

In the tests the following were used:

- K1 conventional muller fully loaded
- K2 conventional muller 40% loaded
- W1 counter-current intensive mixer with 750 rpm rotor
- W2 counter-current intensive mixer with 1500 rpm rotor.

The sand was mixed with 1% bentonite and 4% moisture – Exhibit AO clearly shows the effect of the high speed rotor. The short mixing time is also illustrated in Exhibit AP.

The intensive mixer reaches maximum specific energy input after 90 seconds. After this time, however, further mixing imparts only heat into the sand mass. An average temperature rise of 4.5°C is considered normal over each batch but this can rise quickly if mixing is continued, leading to difficulties at the moulding machine.

Aerators

Aerators or revivifiers, as they are sometimes known, are essentially mixers used to produce a uniform fluffy sand that will give moulds a uniform density.

The basic construction is of a fabricated steel framework, often with a rubber cover and sidewalls to resist sand adhesion and wear.

A belt driven shaft fitted with multiple blades at the sand entry end effectively mixes and blends the sand.

Some aerators are fitted with twin rotors. The first rotor moves the sand in the zone of the second rotor. It is claimed that this design gives far superior results to the standard single rotor version.

Aerators are most usually fitted over the belt that conveys sand from the mixer to the moulding machine.

Aerators fitted on to the belt before the main sand mixer can, in conjunction with a measured amount of water sprayed on to the sand, operate as a pre-blender by activating the clays resident in the recirculated sand. This can, in some circumstances, result in shorter mixing times or stronger blends of sand out of the mixer.

g) Moulding

Recent improvements in moulding machines, the introduction of automatic moulding and the demands for higher productivity have greatly increased the requirements for greensand to be able to cope with these demands. The quality and formulations have been progressively improved to meet the more stringent requirements of today.

Foundries must place great emphasis on maintaining their equipment to obtain optimum sand properties and mould quality.

(i) Ramming

Hand ramming and pneumatic wind ramming are still used in jobbing work in greensand foundries, particularly on larger type jobs and the 'one offs'. However, although many excellent castings are produced by these methods, results can be somewhat inconsistent due to variation in operators.

(ii) Jolt-Squeeze

The predominant moulding method in greensand for many years, where the sand filled moulding box is jolted for several seconds to ensure initial compaction of sand and then a squeeze pressure is applied for final compaction. Jolt and squeeze are often used together for compaction. Even distribution of the sand into the moulding box is important in this process and generally a box frame is used to ensure sufficient sand is available. The more flowable the sand, the better the operation.

A pin lift or roller lift system is employed to lift the box from the pattern and must be properly aligned to ensure good mould quality.

Modern technology has improved this system to automatic operation, where the squeeze pressure can be applied by individual multi-piston squeeze heads over the box

area, either pneumatically or hydraulically controlled, with varying squeeze pressures for outer and inner feet. This allows for pattern depth, etc, and helps to ensure a mould of reasonably uniform hardness. Again, sand distribution in the box is very important.

(iii) Shoot Squeeze

This method is being used extensively in greensand automatic moulding to produce flaskless moulds on the male/female matchplate principle, where the sand is blown into the chamber between male and female pattern plates, which then either both squeeze inward, or more generally the rear plate squeezes under pressure to the static rigid front plate. Variations on this may be vertical squeeze, squeeze or standard one plate squeeze.

Sand for this operation is usually far stronger than normal, with green strengths in excess of 1400 g/cm^2 (20 psi). However, as good shake-out is required, high hot strength with low dry strength must be a characteristic of the sand to ensure almost total reclamation.

(iv) Strickling

This is used very little nowadays, other than for specific types of castings.

A loam sand is normally employed, backed up by various mechanical means and utilising straw, rope, ashes, etc, as fillers.

A skilled moulder is required to ensure good quality and although much of this work has been replaced by modern cold-setting processes, pattern costs can be a deterrent and therefore strickling is still used.

h) Moulding Machines

(I) Introduction

Moulding machines are found world-wide in many forms with outputs from a few moulds per hour to over 400 moulds per hour and with sand consumption up to 150 tonnes per hour.

Essentially all machines share the same function, that is to compact greensand of a specific moisture content, around a pattern. After removal of the pattern, the compacted sand will withstand the erosive force of the metal poured into it.

Progress has been achieved with the advancement of greensand technology, and the development in hydraulic and electronic content.

This section of the guide investigates the choice of moulding systems available today.

(ii) Jolt-Squeeze Machines

These basic moulding machines comprise three main components. A pattern plate onto which is located the pattern being used, a jolt cylinder which is fitted onto and below the pattern plate, and a squeeze cylinder located on a head above the pattern plate.

In operation, a flask fitted to the pattern plate is filled with sand from an overhead hopper or belt.

The pneumatically operated jolt cylinder raises the pattern/flask assembly. The air is then exhausted which then allows the assembly to free fall under its own weight against a stop. This operation is repeated a pre-set number of times in a rapid manner, imparting a degree of compaction to the sand in the flask. The sand density is greatest nearest the pattern face and reduces further away from it. It is for this reason that additional compaction is obtained by either a single hydraulic or pneumatic squeeze plate or by a compensating head as shown in Exhibit AQ.

The machine can be operated with initial jolt followed by squeeze or both simultaneously.

Although traditionally regarded as low output and noisy in operation, modern machines exhibit greatly reduced noise levels, typically around 85 dB(A) compared to over 100 dB(A) for older machines. Rapid pattern change facilities are also available on certain machines.

(iii) Shoot Squeeze Method

This is typified by the moulding machines manufactured by Fritz Hansberg, which employ three distinct phases in the production of each half mould.

Pre-filling Phase

During this phase, prepared moulding sand is sieved onto the entire pattern surface through a fine steel mesh that is fitted inside a vibrating frame. This pre-fill operation gives a number of benefits, such as good surface definition, reduction of pattern wear and elimination of pattern venting. It also enables moulding sand of a different quality to be used for pre-fill and back-fill operations.

Approximately 15% of the flask volume is used for pre-fill.

Shoot Phase

The opening of the shoot valve allows compressed air, which has been stored in the tank head (reservoir) to travel through the shoot filter which contains sand. The column of sand is shot into the flask underneath ensuring compaction by utilising the kinetic energy of the sand travelling at 15 m/s.

Compressed air from this phase is exhausted through vents in the upper part of the shoot frame.

Squeeze Phase

By means of an hydraulic cylinder, the machine table and pattern plate assembly is raised to obtain uniform density throughout the mould. Typical surface strengths are reported to be in the 40–140 N/cm² range.

Typical of the high production moulding machines produced by Hansberg is a four station rotary version which produces alternate cope and drag moulds, giving a production rate of 200 complete moulds per hour. Box size 900 mm x 700 mm x 225/225 mm.

(iv) Impulse and Squeeze Compaction

One manufacturer who produces machines using air impulse and squeeze compaction technique is the Spanish company, Loramendi. The squeeze operation employed in this machine is shown in Exhibit AR.

Compressed air is held in a receiver above the moulding machine before being released to cause an air shock wave. This compacts the waiting sand onto the pattern.

Further compaction is achieved by the downward operation of a hydraulic cylinder resident inside the pressure vessel. The machine can be operated either in the air shock alone mode or with the additional press facility.

(v) Air Flow and Squeeze Moulding

The Seiatu air flow squeeze moulding process promoted by Heinrich Wagner Sinto obtains compaction in two stages, air flow and subsequent squeezing – Exhibit AS. The horizontally parted moulding boxes are fitted onto two tables that rotate about a central column. One table holds the cope, whilst the other holds the drag.

A measured quantity of sand is deposited into the pattern flask and filling frame assembly (1). The machine table lifts this assembly hydraulically and presses it against the squeeze head. The complete mould cavity is therefore sealed and pressure tight.

The Seietsu valve is opened for a short time which allows the compacting air to flow through the sand in the direction of the pattern to escape through vents fitted in the pattern equipment (2).

The airflow produces a downward pressure on each sand grain resulting in good filling of the mould cavity.

As the resistance to air flow increases with rising compaction, so does the pressure on the sand, resulting in a high compaction nearest the pattern surface.

In order to ensure complete compaction, the multi-ram press is activated (3). This is made up of many double-acting hydraulic cylinders fitted with rectangular feet, which ram the sand and give the mould its final strength.

Alternatives to the multi-ram system are the single flat squeeze plate, flexible squeeze plate and water filled squeeze bags.

The moulding machines manufactured by BMD (part of the DISA group) using the “Dynapuls” process operate as shown in Exhibit AT. The moulding box is filled with loose moulding sand (1) before being placed under the compaction unit which contains a large number of pneumatically operated cylinders. The cylinders which are spaced at approximately 120 mm centres, are fitted with ramming rods, of 50 mm to 60 mm centres, which protrude through a pressure plate at the base of the compaction unit (2).

Each cylinder has its own air supply set at the appropriate air pressure that will give the optimum compaction of the sand around the contours of the pattern.

The compaction unit descends rapidly onto the moulding box compacting the sand beneath the rams with the pressure plate compacting the sand between the ramming rods (3).

The amount of compaction around the pattern can be varied by changing the velocity at which the compaction unit hits the sand.

Exhibit AU shows the variation achievable from velocities between 0.5 m/s to 4.7 m/s. The pressures of the ramming cylinders can be set to the optimum pre-load figures by the use of perforated template. This template, which fits over the pattern equipment, is fitted with measuring rods which follow the contours of the pattern. Each rod is marked

off with different colours which correspond to the required setting pressure of each ramming rod.

Kunkel Wagner market the Airpress Plus moulding machine, which operates on similar principles.

(vi) Vacuum Squeeze Moulding

Several manufacturers, including Kunkel Wagner, supply moulding machines operating on the vacuum squeeze or “Vacupress” process – Exhibit AV. By creating a partial vacuum of between 0.3 and 0.4 bar in the moulding chamber, previously metered sand held in an overhead hopper is accelerated towards the pattern plate which provides initial compaction.

Final compaction is achieved by a high pressure squeeze from a multi-ram head being positioned over the mould chamber. As this takes place, fresh sand is metered into the overhead charge hopper ready for the next moulding cycle. Some of the benefits of this system are claimed to be the elimination of vents and uniform mould compaction.

By combining both vacuum moulding, and the option of air flow and multi-ram squeeze one manufacturer markets the Variopress machine. This gives the operator the choice of the compaction flexibility that will best suit the particular pattern in use.

Machines are available with box sizes from 550 mm x 650 mm up to 1100 mm x 1300 mm and outputs from 130 to 90 moulds per hour respectively.

(vii) High Pressure Flaskless Moulding

As the name suggests, this method of making moulds is achieved without the use of cope and drag boxes to retain the sand from initial shape formation through to pouring and casting extraction.

Both horizontally and vertically parted moulds can be produced with both modes of manufacture having their followers.

Horizontally Parted Moulds

Probably the most widely known manufacturer of machines of this type is the Hunter Automated Machinery Corporation situated in the United States, with their “matchplate” moulding process.

A matchplate is a pattern plate with patterns for both cope and drag mounted on opposite faces of the plate.

Both cope and drag halves of the mould are filled with prepared sand in the machine, before being brought together for the high pressure squeeze with simultaneous vibration phase to compact the sand.

The completed mould is eventually pushed out of the machine onto a shuttle conveyor, the bottom of the mould sitting on a “bottom board” to facilitate ease of progress along the conveyor.

From the start position shown in Exhibit AW the matchplate is turned through 180° as the sand hopper above the machine is filled with a measured quantity of prepared sand. Both halves of the prepared mould are brought together.

Part (2) shows the sand being discharged through aerators into the drag flask in the machine while vibration of the flask is being carried out.

After a bottom board is positioned on the base of the flask and clamped in position, the flask is turned back through 180°.

In (3) the sand hopper is being charged with fresh sand, and the previously prepared mould is in the lowered position awaiting its removal from the machine.

The hopper car in (4) has moved across to the cope position as the completed mould is indexed out of the machine.

Part (5) shows the cope being filled, after which the high pressure squeeze is initiated (6).

The matchplate is then stripped (7), before returning to its start position.

Mould sizes available with the Hunter machines are from 355 mm x 483 mm x 140 mm x 114 mm up to 762 mm x 813 mm x 305 mm x 279 mm. The maximum production rate on the smaller machine is quoted as 200 moulds per hour, while on the largest machine 120 moulds per hour can be expected.

Also available for horizontally parted flaskless moulding is the Disa-Forma machine from Denmark, with outputs rated at 150 moulds per hour, and the Haflinger Quattropress machine.

Vertically Parted Moulds

Perhaps the most well known manufacturer of machines in the flaskless vertically parted sector is Disa A/S operating as shown in Exhibit AX.

One pattern half is fitted onto the end of a hydraulically operated squeeze piston with the other half fitted to a swing plate, so called because of its ability to move and swing away from the completed mould.

Sand from a supply hopper above the machine is blown into the moulding chamber by means of a variable pressure compressed air supply stored in a nearby air receiver.

Vacuum can be applied to the moulding chamber to vent air and assist in drawing sand into deep pattern recesses.

Both halves of the pattern are hydraulically squeezed together to compress the sand block. As the swing plate moves away, the piston pushes the new mould to join ones previously made, to form a continuous mould string.

Flexibility is available through variable mould output, variable mould thickness, fast pattern change and core placing options. Varying degrees of control sophistication are provided dependent on the model chosen.

Also available is the Japanese made KOYO machine which operates on similar principles to the Disamatic.

Horizontally Parted Vertically Produced Flask less

An interesting variant on the vertical/horizontal design of flaskless moulding is the Japanese made Tokyu machine (Exhibit AY).

Although the finished moulds exit from the machine in the horizontally parted plane, they are produced vertically using a matchplate pattern.

Exhibit AZ shows the operating sequence of the AMF IV machine which is typical of the range of models manufactured.

Twin cope and drag flasks are able to rotate around a central column so that moulds are blown on one side of the machine (head side), whilst the other side is available for core insertion, mould closing and stripping (push-out side).

The starting position shows the prepared mould halves separated from the matchplate, with the strip side empty.

As the table rotates, the empty flasks are presented around the matchplate and the prepared mould halves ready for closing.

The flasks on the head side are closed on to the matchplate and turned through 90° where the mould is blown and squeezed.

The flasks are returned to the horizontal plane for pattern stripping on the head side and mould closing and stripping on the push-out side.

A schematic of the mould blowing mechanism is shown in Exhibit BA. Sand is blown through directional or rectifier plates into waiting flasks.

Where the pattern profile is such that “shading” of poor sand compaction could occur at the bottom of the pattern, additional blowing is available from the rear of the squeeze plates. Guide plates under the pattern can also assist in obtaining optimum sand density.

The largest machine available can produce 200 moulds per hour in the 610 mm x 508 mm x 130 mm–200 mm size range. A maximum core setting time of nine seconds is available.

(viii) Reclamation

Greensand, under normal conditions, should give high levels of reclamation, with sufficient new sand addition to maintain properties.

The process is fairly simple and if contaminants such as scrap metal, etc, are removed there is generally little problem other than temperature variation, which can hinder consistency. Whenever possible, foundries must endeavour to utilise methods of cooling return sand, in order to present it to the mill at consistent temperature levels.

Care must be taken with selection of core binders in order to prevent a build-up of unwanted contaminants. Again, it is essential that new sand be added on a consistent basis.

(ix) Dry Sand

The use of dry sand has been reduced drastically in recent times, due to the advent of cold setting processes, which have eliminated the need for expensive drying operations and have decreased production times dramatically.

Basic Principle

A mixture of sand, clay and water, plus other additives as required, are correctly mulled, moulded and thoroughly dried to produce a mould suitable for casting.

Major Criteria

The major criteria of dry sand are the same as for greensand with variations in the addition rates for the specific requirements of the process.

Intricate large moulds were difficult to cast to accurate dimensions in greensand and dry sand was introduced to overcome this.

Dry sand is generally used in steel casting production, particularly with stainless where the results have been good and the higher cost factor is of less importance. Generally, moisture and clay levels are higher in a dry sand mix with the clay 10% or more. Occasionally, fireclay is used as part of the clay addition to complement a Wyoming Bentonite. The higher clay levels also help prevent expansion defects.

When the sand has been mixed and moulded, the moulds are baked in an oven or stove at temperatures of 300–600°C with particular care being taken in the drying time, otherwise the moisture will not be dissipated. Drying time is determined by the size, weights and section thickness of the moulds being made.

It is more expensive than greensand due to the extra additive costs, the need to use stoves or ovens to dry thoroughly and far slower production times.

Its advantages are stronger moulds, which are easier to handle; far less moisture to give steam related defects such as expansion scabs; more dimensional accuracy and, as coatings are generally used, a very good casting finish is often obtained.

5.4 Chemically Bonded Sand

In the Western European foundry industry, chemically bonded moulds are predominantly manufactured using self-set systems. Heat-cured and gas-hardened organic systems are normally used for the production of small components that require better surface finish and dimensional accuracy.

a) Binder Systems

Foundries can choose from a large range of binder systems, with new products being launched at regular intervals. Over 400 different products are available, many of which can be assigned to a generic binder group as shown in Exhibit BB.

The binder costs incurred by a foundry also depend on the proportion of binder added to the sand. Each foundry should establish its own optimum levels of additions based on mould handling and casting quality. Typical addition rates are shown in Exhibit BC.

Foundries tend to add excess binder to ensure adequate safety margins, but modern mixers can give better control. Where binder additions are excessive, the rate of hardener addition will also be increased, leading to unnecessarily high production costs.

Optimising resin and hardener additions will give:

- significant cost savings
- reduced environmental emissions
- improved sand reclaimability
- reduced scrap and casting repair.

With a gas-hardened system, 0.25 tonnes of carbon dioxide per tonne of binder should normally be sufficient. Although carbon dioxide is relatively cheap, optimising its use could produce significant savings.

Methyl-formate and amine gases used in organic gas-hardened systems are considerably more expensive. Moreover, Volatile Organic Compound (VOC) emissions to the atmosphere are a major environmental concern.

Gas consumption can be reduced by:

- improving understanding of binder chemistry and the generation of vapour
- minimising and controlling the gassing rate
- ensuring that the pattern box is gas-tight
- improving venting arrangements.

There is considerable potential for cost savings in this area, with an associated reduction in environmental impact.

b) Acid Set Furan Binders

A group of versatile cold setting organic binders, all based on furfuryl alcohol and which occupy a prominent place in core production techniques.

(I) Basic Principles

There are three types of cold setting furan binders of commercial significance containing furfuryl alcohol contents ranging from 30–85%. The resins may be classified in chemical composition terms as follows:

- Urea formaldehyde/furfuryl alcohol – UF/FA

- Phenol formaldehyde/furfuryl alcohol – PF/FA
- Urea formaldehyde/phenol formaldehyde/furfuryl alcohol – UF/PF/FA.

Furfuryl alcohol/formaldehyde (FA/F) resins are rarely used as sole binders, but are sometimes employed to enhance the properties of the above resins.

All types are polymerised by addition of acid and characteristically yield densely cross-linked structures with excellent bonding properties.

The acids used are:

- Phosphoric acid
- Aromatic sulphonic acids, commonly paratoluene sulphonic acid (PTSA) and more reactive types such as xylene sulphonic acid (XSA) and benzene sulphonic acid (BSA).
- Blends of inorganic acids, commonly phosphoric and sulphuric acids and blends of sulphonic acids and sulphuric acid with relatively small proportions of the latter.

(ii) Binders

UF/FA

This group contains between 40% and 85% furfuryl alcohol and is characteristically highly reactive, providing excellent strength and through cure features. Binder performance increases with FA content and an accompanying fall in nitrogen content. A 50% FA binder contains about 9% nitrogen and can be used for non-critical iron castings, whereas at 60% FA and nitrogen of about 7%, the binder serves well for general purpose iron castings. Binders of 80% plus FA have nitrogen levels below 3% and may be used in iron foundries reclaiming sand. In non-ferrous applications, where nitrogen is unimportant, selection is on cost/performance basis.

PF/FA

These binders have FA contents ranging from 30% to 70% and have good performance in through cure and cold strength development and improved hot strength compared with UF/FA. PF/FA resins can produce brittle cores if used with new sand and have a tendency for finning and thermal cracking. Complete freedom from nitrogen is a major attraction for steel and high duty iron castings, where sand is reclaimed and maximum protection against nitrogen pinholing is required.

UF/PF/FA

This group varies in FA levels between 40% and 85% and can be viewed as UF/FA binders, with partial replacement of UF with PF resole resin, thus reducing nitrogen level. They therefore exhibit low nitrogen levels, yet maintain reasonable strength properties compared to a UF/FA counterpart.

(iii) Catalysts

Phosphoric acid and phosphoric/sulphuric acid blends are only recommended for UF/FA and FA/F resins. Reclamation is possible with these catalysts but build-up of phosphates can yield poor strength, reduced refractoriness and possible phosphorus pick-up in the metal.

UF/FA resins containing high FA contents and PF/FA and UF/PF/FA resins usually employ catalysts based on sulphonic acids, commonly PTSA. These sulphonic acid catalysts are particularly suited to sand reclamation due to ease of burn-out during casting. Blended catalysts or reactive XSA and BSA are frequently used when more rapid strip times are required.

(iv) Sand

Sands of AFS 40–90 (375–150 microns average grain size) are suitable, with the granulometry largely dictating the binder level necessary for adequate strength.

Low acid demand is required to avoid poor performance or the need to use excessive catalyst levels. Consequently, olivine and some grades of chromite sands are unsuitable for some furan binders.

(v) Mix Composition

The binder level based on sand is typically 0.8–1.5%, but the low viscosity characteristics frequently allow adequate performance within the range 0.6–1.0%.

Catalyst levels vary considerably and are dependent on several factors, but usually fall in the range 25–70% of the binder.

(vi) Mixing Equipment

Trough and high-speed continuous mixers are ideal for furan binders. The self-cleaning, high speed variety are recommended for setting times of less than ten minutes. Batch

mixers can be used but careful consideration must be given to the bench life of the mixed sand.

(vii) Coatings

A wide range of coatings can be used, including water, alcohol and chlorinated solvent-based, applied by brush, spray or flooding techniques.

Alcohol-based coatings can cause softening of the surface of the mould or core if applied too early after stripping. As an approximate guide such coatings should not be applied within a half hour of stripping and should be fired immediately.

(viii) Casting Performance

Surface Finish – furan binders are capable of yielding good casting surface finish.

Penetration – generally not a problem with furans.

Gas Evolution – nitrogen porosity is the major potential problem with furans containing UF resin. Transfer to PF or FA/F, or nitrogen-free PF/FA overcomes the problem. The nitrogen content of the reclaimed sand must be controlled at 0.15% maximum for grey iron and lower levels for steel and ductile iron.

Erosion – the erosion resistance of furans is generally good and increases in line with the hot strength of the binder. Erosion resistance improves from UF/FA to PF/FA and with increase in FA levels.

Breakdown – this is generally good compared with other organic systems and improves with increase in nitrogen content in UF/FA binders. PF/FA shows poorer breakdown than UF types.

Veining – PF/FA binders of high PF content are more susceptible to veining than other furans due to low plasticity. Addition of UF may resolve the problem. Use of reclaimed sand reduces veining. Accurate catalyst additions are important.

Hot Tearing – low levels of reactive sulphonic acids, eg XSA, should be used in place of high levels of PTSA to avoid sulphur build-up in reclaimed sand leading to hot tearing in steel castings.

(ix) Reclamation

Sand reclamation is widely used with this type of binder. Three main variables need close monitoring and control: nitrogen content, loss on ignition and gas evolution.

To avoid nitrogen porosity problems, the following maximum levels in rebonded reclaimed sand should be used as a guide.

It should be noted that phosphoric acid via ammonium phosphate formation can increase the amount of nitrogen present in the sand. Use of phosphoric acid with continuous use of reclaimed sand can cause a pitting defect in heavy section ferrous castings. Loss on ignition should be controlled at 2.5–3.5% for grey iron and 2.2% max. for steel. Gas evolution for grey iron should be below 20 cm³/g and for steel below 10 cm³/g.

c) Acid Set Phenolic Resoles

Acid hardened phenolic resin binders were introduced first in the early 1970s because of the shortage of furfuryl alcohol. They have now established a relatively small niche market in most countries in the world.

(I) Basic Principles

A phenolic resole resin is catalysed by the addition of sulphonic acids.

Sand is mixed with acid followed by resin, used immediately and allowed to set at room temperature.

(ii) Sand

Because setting occurs under acid conditions, low acid demand of the sand is very important.

Clay and shell containing sands should be avoided.

Reclaimed sands require slightly lower resin levels and less acid because the set resin has filled surface porosity and is acidic in nature.

Acid catalysts are chosen to give the setting range required and are often altered from a weaker acid in summer to a stronger acid in winter to accommodate ambient and sand temperature changes.

Sand temperature control by heaters in the winter and coolers in the summer also helps to establish consistent setting times and strengths, the recommended temperature range being 20–25°C.

(iii) Mixers

Batch mixers are not normally recommended for cold setting phenolic binders.

Continuous mixers are ideal, particularly the high speed self-emptying and self-cleaning types. This enables short set time systems to be used and assists materials having a poor bench life/strip time ratio.

Phenolic/acid systems have a lower bench life/strip time ratio than furan resins (both UF/FA and PF/FA types). Both of these are lower than phenolic urethanes.

However, once the characteristics are recognised, they can be handled and used very successfully.

(iv) Refractory Coatings

Alcohol-based refractory coatings cause some softening back of the core or mould surface if applied too quickly after stripping. At least one hour waiting time is required to allow the bond to harden before application of refractory coatings. Special refractory coatings based on hydrocarbon solvents have been developed that allow early application, but have the disadvantage of giving off more smoke on ignition.

Acid hardened phenolic resins are softened back more than acid-cured furane resins by alcohol-based refractory coatings. Aqueous-based and evaporative refractory coatings are both applicable to acid-cured phenolic moulds or cores.

(v) Casting Performance

Generally, acid hardened phenolic resins behave like furan resins. They give a rigid bond, a tendency to cause hot tearing, no erosion, slow breakdown, a reasonable surface finish, no penetration or burn-on, no lustrous carbon or nitrogen pinholing, but some carbon pick-up. Sulphur dioxide evolution on casting is a major problem, particularly on reclaimed sand.

(vi) Sand Reclamation

Up to 90% reclamation can be achieved by the attrition method.

d) Alkyd Urethane Resin Process

This binder process was introduced in 1965 as an improvement over the baked oil system.

(I) Basic Principles

The process is a three part system comprising a drying oil modified alkyd (polyester), a polyisocyanate and a catalyst. The catalyst which controls the speed of cure is commonly incorporated into the alkyd.

(ii) Sand

The alkyd-urethane system is generally less sensitive to sand type and chemical composition. Round grain sand with low levels of contamination is recommended for good reproducible results. A moisture level of more than 0.25% results in a low cure rate and reduced strength value. The binder system is well suited to special sands such as olivine, zircon and chromite.

Changes in sand temperature have a marked impact on cure rate with strip time varying as much as 1 minute per 1°C.

(iii) Mix Composition

This will vary depending on grain fineness, but is typically at 1–1.5% total binder. The isocyanate component is normally used at 18–20% of the weight of alkyd. When the catalyst is added separately, this is usually 3–8% of the alkyd weight depending on the desired strip time.

(iv) Mixers

Continuous mixers are well suited to the process, especially for heavy work. Batch mixers can be used but overmilling should be avoided to guard against rise in sand temperature.

(v) Strip Features

The nature of the curing reactions produces an initial plastic stage which gives excellent stripping properties.

The bench life to strip time ratio is about 1:2.

(vi) Casting Performance

Casting surface finish is generally excellent, though hot strength is lower than with other organic cold set binders. The addition of 2–3% iron oxide improves casting properties and reduces problems such as porosity and lustrous carbon.

(vii) Refractory Coatings

Water, alcohol and chlorinated solvent-based coatings can be used.

With medium-sized work, water-based coatings should not be applied within four hours of stripping and it is advisable to dry immediately

For large castings, the alkyd urethane binder should be allowed to cure for at least 24 hours before applying any type of coating. Alumina and/or zircon-based coatings have proved very satisfactory for large castings.

e) Ester Hardened Alkaline Phenolic Resins

The fact that alkaline phenolic resins could be cross-linked to form a gel by the addition of an ester was discovered in the early 1950s but it was not until the early 1980s that these materials found application as environmentally improved foundry sand binders.

(I) Basic Principles

The alkali in the phenolic resin reacts with the ester to form the alkali metal salt of the acid component of the ester releasing the alcohol component. Phenolic resin is released in a reactive form that polymerises (gels) at room temperature.

(ii) Sand

Because of its alkaline nature, the phenolic ester system is suitable for most types of sand, including the alkaline types, eg sea sands, clay bearing sands, olivine, chromite and zircon. This is a significant advantage over the acid curing systems. The normal relationship applies between grain size, shape and distribution, surface cleanliness, etc, and strength. For normal core and mould purposes, sands having an AFS number from 45–80 (325–175 microns average grain size) are used. Use of coarse sands requires a refractory coating to enhance casting finish.

Sand Temperature – control by cooling in the summer or heating in the winter does much to reduce the variability in setting and strip time obtained from a phenolic/ester system. However, since most foundries are not convinced that expenditure on this equipment is essential, it is necessary to vary the type of ester used, dependent upon the sand temperature. Blend pumps are available that can blend a reactive and a less reactive ester in varying proportions to adjust reactivity.

(iii) Mixer

Phenolic/ester systems can be mixed in any normal continuous or high speed mixer. It is possible to add either the resin or the ester first onto the sand. It is normal practice to add ester first as early as possible in the sand stream. Blade wear should be checked regularly, adjustments made and ‘hold back blade’ angles adjusted to ensure adequate mixing with no spotting (i.e. undispersed resin).

Resin Addition – 50–60 AFS silica sands require from 1.2–1.5% addition of resin. 15–25% ester of the resin weight is added depending upon type. Zircon sand with AFS 70–80 (200–175 microns average grain size) requires 1.0–1.25% addition of resin, chromite sand 1.0–1.5% and olivine sand 1.5–2.0%.

It is important to check that the feed lines, non-return valves and pump components used with the resin and ester are not attacked. Viton A and aluminium should be avoided as they are attacked by the resin.

(iv) Refractory Coatings

Water-based Refractory Coatings – the surface of the mould or core should be pre-warmed by torching, taking care not to blacken the surface. A water wash should be applied by spraying, painting or dipping. Re-dry by further torching or in an oven if the size of the core or mould permits. Avoid wet spots.

Alcohol-based Fired Refractory Coatings – care should be taken not to apply the coating until the surface of the mould or core is hard. If in doubt torch dry. The alcohol should be fired immediately. Do not allow to air dry. Ensure that all the alcohol has burnt off from deep mould draws.

Chlorinated Solvent-based Air Drying Refractory Coatings – follow manufacturer's instructions taking care not to inhale the solvent fumes.

(v) Reclaimed Sand

The phenolic/ester system can be reclaimed at levels up to 80% using any of the conventional dry attrition units, wet reclaimer or pneumatic reclaimers. A special resin/ester has been recently developed which will reclaim at levels of >90%. Loss on ignition of 1–1.5% is usual with 0.15% maximum retained alkali.

Limited amounts of reclaimed sands from other processes can be added to phenolic/ester sand but tests must be carried out in the laboratory to determine the tolerable levels.

(vi) Casting Performance

Generally good with indications of hot tearing on specific steel castings.

f) Ester Hardened Silicates

The ester-silicate system has been in use since the 1960s and offers several advantages, most notably from the environmental standpoint. It is a versatile binder process finding wide application for small and heavy castings in a variety of metals.

(i) Basic Principle

Bond formation is achieved by chemical reaction between sodium silicate and (indirectly) the organic ester. Further significant bond strength is attained by subsequent dehydration of the silicate gel.

(ii) Sands

Clay-free silica sand of moisture content 0.5% maximum is ideally suited to ester silicate binder. The system also works well on olivine, zircon and chromite sands; even sea sands may be successfully used.

The reaction rate of this binder system is particularly temperature sensitive and control of sand temperature to 25–30°C, in the extreme 15–35°C, is advised.

(iii) Mix Composition

Silicate additions are commonly in the range 2–4.5% with the ester level being 10-15% based on silicate. Setting times cannot be reduced by raising ester levels above recommended values and will impair performance. Setting times should be varied by a change in ester.

(iv) Mixers

Continuous or screw type mixers are well suited to the process, especially for heavy work. Batch mixers can be used, but overmilling and subsequent rise in sand temperature should be avoided. Ester should be added first and mixed briefly before addition of silicate.

(v) Refractory Coatings

Alcohol and chlorinated solvent-based coatings may be used and applied by swab, brush, spray or overpour. Importantly, with this process powder coating can be applied successfully by the electrostatic technique. Water-based coatings are not recommended because of adverse effects on bond strength.

(vi) Casting Performance

Surface Finish – excellent strip and glass-like surface usually provides for good casting finish.

Penetration – problems are minimal.

Burn-On – with heavy section castings and high pouring temperatures it is advisable to coat with refractory dressing.

Metal/Mould Reaction – there is little chance of such reaction since the system is free of nitrogen, sulphur and phosphorus. Gas evolution is low.

Erosion – good resistance to this defect.

Breakdown – poor. Not as good as organic binders, but suitable for many purposes if based on formulated silicate containing breakdown agent.

Hot Tearing – generally good.

Veining – no problems.

(vii) Sand Reclamation

Where reclamation is used, this is commonly by the dry attrition method, but only 50% of reclaimed sand can be achieved. Residual soda levels limit higher usage rate since above about 0.8% refractory characteristics are impaired. Wet reclamation permits higher levels of sand re-use but at a significant cost penalty.

Modern hardeners based on carbonate esters permit more efficient detachment of residual silicate film via an embrittlement mechanism. Lower soda levels can, therefore, be achieved by dry attrition and allows higher sand re-use levels. This is particularly beneficial to steel casting in expensive zircon sand.

g) Phenolic Urethane Cold Set

(i) Basic Principle

A liquid polyol (Part 1), almost exclusively benzylic ether linked phenolic novolak is mixed with a polyfunctional isocyanate (Part 2) in the presence of a liquid tertiary amine catalyst (Part 3). The catalyst promotes reaction between the hydroxyl and isocyanate groups to form a three dimensional cross-linked mass bound together by urethane bonds. The catalyst is a true catalyst and remains unchanged after the reaction. Reaction speed (cure time) is controlled by selection and quantity of tertiary amine catalyst used, the preferred catalyst being phenylpropylpyridine.

(ii) Sand

Silica sand is in general use, but other sands such as zircon, olivine and chromite may be used. It is essential that the sand is dry since any moisture will react with isocyanate groups and lower the final strength of the sand mass. The normal relationships between grain size, shape and distribution, surface cleanliness and impurities apply. Sand with AFS number 45–80 (325–175 microns average grain size) is used for core production. Casting finish is enhanced by application of refractory coating if coarse sands are used.

Sand Temperature – for consistent set and strip times sand temperature variation should be minimised by heating or cooling depending on the season. If this is not

achieved, then it will be necessary to alter the quantity of amine catalyst in the sand/resin mixture.

(iii) Mixer

Because this is a three component system (phenolic resin, di-isocyanate, tertiary amine), batch mixing can be used, but continuous mixers are normal when three pumps are available. However, it must be stressed that the catalyst component is present at low levels and accuracy is essential to ensure effective control over the setting time. The catalyst should be metered into the resin stream immediately prior to entry into the mixer trough.

Resin Addition

50–60 AFS silica sand requires:

0.5–0.75%	phenolic resin
0.5–0.75%	di-isocyanate
0.02–0.06%	catalyst

70–80 AFS zircon sand requires:

0.4–0.5%	phenolic resin
0.4–0.5%	di-isocyanate
0.016–0.02%	catalyst

Olivine sand requires:

0.6–0.9%	phenolic resin
0.6–0.9%	di-isocyanate
0.024–0.072%	catalyst

Chromite sand requires:

0.4–0.6%	phenolic resin
0.4–0.6%	di-isocyanate
0.016–0.024%	catalyst

The modern tendency is to combine Parts 1 and 3 into one component for use with the di-isocyanate.

(iv) Refractory Coatings

In many cases refractory coatings are not required, but the preferred refractory coating is alcohol-based. At low dilution too much alcohol is taken into the sand which on flaming off may produce a friable surface. Air drying of alcohol coatings is preferred.

Water-based coatings can reduce the strength of the core or mould if the resin system has not been effectively cross-linked. Halogenated air drying coatings are effective but are now falling into disuse for environmental reasons.

(v) Reclaimed Sand

Up to 95% dry attrition reclaimed sand can be used, but is essential to keep the loss on ignition to less than 3% because nitrogen build-up may produce casting problems.

(vi) Casting Performance

Surface Finish – this is usually excellent without the use of a coating but lustrous carbon defects may occur in iron casting, especially on ‘deep sided’ or flat shaped castings. It is possible to get good and poor surface finish on the same casting. Rapid, non-turbulent filling and an imbalance of resin in favour of Part 1 can reduce the occurrence of this defect.

Penetration – this is possible, especially with cast iron due to its long freezing range.

Burn-On – this is generally not a problem.

Mould/Metal Reaction – nitrogen pinholing in steel is possible when high nitrogen content reclaimed sand is used. This can be reduced by the incorporation of up to 3% iron oxide in the sand. Refractory coatings give adequate protection against carbon pick-up.

Erosion – this may be a problem under some casting situations, but is generally not present.

Breakdown – systems are available that give excellent breakdown with aluminium alloys and with ferrous metals.

Hot Tearing – the process is resistant to hot tearing due to lower rigidity than straight phenolics and its ease of burn-out.

Finning/Veining – this can be a problem with certain formulations under severe casting conditions. Iron oxide may be added to reduce finning.

h) Cement Sands

A blend of washed silica sand, Portland cement and water, mixed in correct proportions which, when set, produces a core of very high strength.

Actual additions can vary, depending upon atmospheric conditions, temperature and size of casting, but are generally in the order of 7–10% cement with 6–8% water. The materials can be mixed in a batch muller or continuous mixer and the resulting mix is used to produce cores as per dry sand practice. Ideal for strickle moulding.

Cement sand has a reasonable working life (up to 1.5 hours), is stripped immediately and, dependent upon size and conditions, takes 2 to 3 days to set.

The major application is for very large jobbing work where its dimensional stability and high strength allows handling of cores by crane, etc, without problems.

It has good chilling characteristics and defect levels are generally low, although the surface finish obtained is often not as good as that obtained with modern, cold set processes.

It can be reclaimed, generally as a backing or stuffing medium for virgin sands.

It is environmentally friendly and there are no disposal problems.

The process is not widespread, but is currently in use in at least two Western European steel foundries, where a combination of water-based and spirit-based coatings is used to assist with strip and casting finish. It is essential that coatings are dried completely.

i) Fluid Sands

(i) Silicates

This process was developed in Russia but has never been a significant process in the West. Sand is produced in a highly fluid state by rapid mixing with foaming agent and can then be poured directly into boxes, avoiding the need for mechanical packing. Di-calcium silicate is used for hardening agent. In this foamed state physical strengths are very low and permeability high, the latter demanding the use of a thick coating to

prevent metal penetration. The process is still used in Russia in the obvious niche area of the production of very large, relatively simple castings.

Heat Curing – since dehydration plays an important role in bond formation of silicates, it is possible to achieve good strength properties by oven baking. Ordinary core stoves and normal temperatures (ca 200°C) can be used and will yield the strongest possible mechanical strength. This method is little used since there is no economic advantage and such high strengths are not always desirable.

(ii) Resins

Basic Principle – the concept of fluid sands was developed to facilitate rapid mould filling originally with silicates for ingot moulds.

The principle is to foam the liquid bond so that its volume expands to exceed the sand volume and the mixture behaves like a mobile slurry. This slurry can be rapidly poured into a mould or around a pattern. No ramming is necessary and the mobility of the mix enables it to fill boxes with undercuts and complicated shapes which are difficult if not impossible to ram.

j) Cold Setting Mould Production

Air-setting chemically bonded systems are based on the ambient temperature curing of two or more binder components after these have been mixed with sand. For a period of time after the initial mixing, the sand is workable and flowable, to allow the filling of the mould flask. Curing begins immediately after all the components are combined.

The sand is mixed in a batch or semi-continuous mixer and transferred to a flask (often made of wood), which can be removed once the hardening process has taken place. The time difference before removal ranges from a few minutes to several hours, depending on the binder system, the catalyst, sand type and the temperature of the sand.

Modern mixers have blender boxes and programmable controllers which assess the sand temperature and automatically vary the binder and catalyst to compensate for this.

One major advantage of cold-setting systems is the use of wooden or plastic pattern tooling. This reduces costs and makes the system suitable for lower-volume production runs and for small foundries.

Systems that obtain the lowest binder levels from low viscosity binders also exhibit the best flowability. The phenolic urethane systems remain flowable until just before the

desired strip time. Other systems show immediate strength build-up from the time of mixing.

High sand temperatures accelerate the cure, thereby reducing work/strip time. Generally, for each temperature increase of 10°C, work time/strip time is cut by 50%. Sand temperatures in the 27–32°C range are typical for most no-bake operations. Temperature extremes should be avoided. At temperatures less than 10°C, the core/mould may not cure completely. At temperatures above 38°C the curing reactions are so fast that overcure is common. Furanes are the most sensitive to undercure/overcure, while oil urethanes are the least sensitive.

Ease of stripping and through-cure properties are critical to the mould maker. Mould breakage and pattern life are significantly affected by this property. Alkyd oils have the best stripping properties and the most plasticity at strip. Phenolic urethanes, ester-cured phenolics and phenolics are the next best. Furanes and silicates are the most difficult to strip and are more brittle when cured. All the systems have good release when a high-quality pattern release agent is used.

Productivity depends directly on cure rate and work time:strip time ratios. Work time is the time for mixing sand with the binder until hardening. Strip time is the time from mixing to stripping of the solid mould. Strip time is determined by the speed of the curing reaction, which also depends on sand temperature.

The ratio of work time to strip time is a measure of potential productivity. The work time: strip time ratios of the phenolic urethane systems exhibit the best productivity.

Automation of air-setting chemically bonded moulding has been achieved by installing facilities in a “loop system” containing a number of elements, such as:

- a vibratory compaction table to assist the filling and give a homogenous block mould
- a semi-continuous mixer
- a series of rollers and turntable units to allow for curing, stripping, flood coating (if required), core setting, rollover and closing before transfer to the pouring and cooling/ knock-out sectors.
- Pattern changes can be achieved quickly using the loop system. To speed up and further automate, the track system can be powered and PLC controlled.

k) Reclamation

Considerable progress has been made in recent years in sand reclamation technology. Landfill taxes in Western Europe mean that it is becoming ever more expensive to dump foundry waste sand, which makes sand reclamation more attractive financially.

When considering the reclamation of chemically bonded sand, a distinction is drawn between primary and secondary reclamation. Primary reclamation, also known as attrition or particulation, is where the sand from moulds or cores is broken down to its original grain size or small particles. The particulation process includes:

- sieving the sand to control grain size
- fines removal
- cooling the sand prior to blending with new sand.

Vibratory grid or screen equipment is the most widely used technique for primary reclamation.

Particulated sand must be mixed with a proportion of new sand to produce a sand mix of sufficient quality for moulding or coremaking. The addition of new sand ensures that the sand mix, when re-coated with binder, has an adequate bench life and sufficient mould strength.

Secondary reclamation techniques involve further processing of the particulated sand to remove residual binder. Foundries using these techniques have virtually eliminated the need for new sand additions and, therefore, minimised sand purchase and disposal costs.

Secondary reclamation is most commonly carried out using pneumatic equipment. The particulated sand is blown against a target plate. The impact and abrasion causes the resin binder to be chipped away from the sand grains. As the pneumatic pressure increases, a greater proportion of the resin binder is removed from the sand. Excessive pressure should be avoided because this may result in fracture and powdering of the sand grains

Other physical methods used include hammer mills for silicate-bonded sands, centrifugal drums and wet scrubbing. There is, however, a growing use of thermal methods, as higher recoveries are possible with these.

Most current thermal reclamation plants are based on fluidised bed systems. Particulated sand and contaminated dust is fed to the plant and forms a bed which is then fluidised and heated. The temperature to which the bed is heated depends on the method used for controlling volatile organic compounds (VOCs), i.e. after-burning or in-chamber decomposition. The hot, treated sand is discharged to a cooler, where the temperature is reduced to an acceptable level. Emissions from the plant are ducted to a bag filter which is fitted with an automatic shaking mechanism for bag de-dusting.

Thermally reclaimed sand has LOI values of less than 0.1%, which makes it suitable as a replacement for new sand.

Thermally reclaimed sands are slightly coarser than new sand because of the presence of some agglomerated grains and some fines removal that occurs during reclamation. Thermally reclaimed sand has almost double the bench life of particulated sand, but a somewhat shorter life than new sand.

Although proven secondary reclamation techniques are available, they are not widely used currently within the Western European foundry industry, partly because of the relatively high capital cost of the equipment. As the costs of sand purchase and disposal increase, however, more foundries will consider secondary reclamation to be cost-effective technology.

Sand: liquid metal ratios are a parameter that can be controlled to optimise sand use and reduce operating costs.

The amount of sand mixed per tonne of metal poured varies for different types of metal and different sizes and shapes of castings. In each case, the amount of sand must be sufficient to ensure adequate mould strength. Once an adequate mould strength has been achieved, there is no additional benefit in using more sand to create a bigger mould.

The optimum sand:liquid metal ratio depends on the density and pouring temperature of the metal. A stronger mould is required to cast denser metal. Similarly, metals which are cast at higher temperatures need thicker moulds to ensure that the mould strength is retained long enough for the casting to solidify.

Although foundries may feel more confident with over-sized moulds, using more sand than necessary only increases production costs. Optimising mixed sand (i.e. sand + binder) consumption has many advantages:

- productivity is increased
- less sand is required, thus sand costs are reduced
- binder costs are reduced because less binder-coated sand is used per casting
- emissions to atmosphere from mixing and casting operations are reduced because less sand is mixed for each casting
- natural reclaim is higher in thermally degradable binder systems because the proportion of burnt-out sand is greater
- burn-out makes particulation easier
- burn-out results in lower residual binder levels in the reclaimed sand, which allows greater amounts of sand to be re-used.

5.5 Other Moulding Processes

a) Shell or Croning Sand

Shell sand was developed in the early 1940s by Johannes Croning as a rapid method for making mortar bombs to the close dimensional accuracy and excellent surface finish required. The application of shell sand grew rapidly through the 50s and 60s and in the mid to late 1970s its use was at its peak in Western Europe.

Initially the system was a mixture of sand, 5–6% of a finely ground novolak resin and a curing agent, but this was soon superseded by coating individual sand grains with the resin and curing agent mixture.

(I) Basic Principles

Novolak resins are prepared by reacting 37–55% formaldehyde solution with excess phenol using an acid catalyst at temperatures of up to 105°C.

After removing water, this yields a thermoplastic phenolic resin which may be in the form of a solid, solution or emulsion.

The novolak resin is coated onto sand at 120–150°C in robust mixers where:

- a) solid resins melt and are distributed over the sand
- b) solutions or emulsions have the carrier solvent driven off as the sand is coated.

Whilst the sand is being coated, a curing agent, hexamethylenetetramine (hexamine for short) is added either as a solid or solution in water, which is distributed throughout the resin. The temperature is insufficient to effect curing.

Lubricant (wax) is added at this stage to reduce the load on the mixer and provide an internal pattern release agent. The wax can be incorporated into the novolak resin. Solid novolaks require an addition of water to induce solidification by dropping sand temperature.

Further processing breaks the agglomerated sand to a free-flowing medium, with individual grains encased in the phenolic resin and curing agent mixture.

The cooled sand is then in a ready state for the production of cores. This sand can then be dumped or blown into hot metal coreboxes where the thermoplastic resin melts and the curing agent cross-links it to yield the required sand shape. Once the required thickness of sand has been melted and partially cured, excess free flowing sand is removed by inverting the core. Complete curing is effected by a further period of time

in contact with the hot patterns and in the case of moulds by a radiant heater on the back face. Subsequent removal is effected by ejection pins. The usual practice is to make two half moulds at the same time and glue them together with a hot curing adhesive.

(ii) Sand

Clean silica sand is the predominant base for shell sand. Both zircon and chromite sands are used in specialist applications to overcome certain casting problems. Olivine sand is not used as it gives low strength.

For moulding sand AFS of 90–110 are normally used.

(iii) Sand Temperature

Normally, the temperature of the sand lies between 5–25°C and has little effect on mould or coremaking. Longer investment and cure times are required as the sand temperatures fall below this range. Storage in bulk tanks exposed to the sun in hot summers may give rise to agglomeration of the sand into lumps which may cause blockage of silos.

(iv) Resin Addition

Coated sand for moulding may have resin levels between 3.5–5.5% of sand weight and depends on the size of the casting and the metal being cast. High levels are used because the mould, which may only be 6–12 mm in thickness, bears the full force of the ferrostatic pressure and thermal shock.

Core sand is produced with lower resin levels, 1.5–3.5%, depending on the AFS number and metal being poured. Cores may be hollow shells or solid. It is essential that gas produced during casting can escape rapidly through the core mass otherwise casting defects may occur. Sand with low AFS number 40–45 and low resin contents are being used more extensively to induce sand breakdown with aluminium and its alloys.

There are numerous types of coated sand available to cater for the wide range of metals cast. Shell sands are available which give good resistance to expansion defects, cracking and orange peel defects. The casting of steels requires special sands with low or zero nitrogen and containing iron oxide (Fe_3O_4).

(v) Release Agents

Although coated sands have release agents incorporated, silicones are used intermittently on coreboxes to give smooth ejection of the cores.

New patterns require special treatment with conditioning agents to build up a film of non-sticking quality onto the metal surface. Cleaning of accumulated resin in coreboxes is necessary to minimise sticking, especially at the transfer port(s).

(vi) Shell Moulding Machines

Shell sand, also known as Croning sand after its inventor, is also used to prepare moulds by both dumping onto heated patterns or shooting/blowing into heated boxes. Both methods utilise a sand pre-coated with a resin binder which will melt, fuse and cure with heat.

Dumping

This method relies on 'dumping' the sand under gravity onto a hot pattern for a period of time, known as the investment time, the length of which controls the thickness of the shell mould. After full heat curing the half shell mould is stripped from the pattern by ejection pins. Two half moulds are joined together either by hot curing adhesive or clamps.

The sequence of operations of a typical shell moulding machine are shown in steps 1 to 7 in Exhibit BD. This shows just one pattern plate in operation.

The pattern plate is rotated 180° to fit onto the dump box which contains the resin coated sand (1 & 2).

The assembly is then rotated 180° at high speed in order that the sand may fall onto the heated plate. Even distribution of the sand is achieved by baffles fitted inside the dump box (3).

A variable pre-set time allows the desired thickness of sand to be built up (4).

The assembly rotates back through 180° to allow the uncured sand to fall back into the dump box (5).

The pattern plate returns to its start position so that a gas or electrically heated curing hood can be located over the plate to fully cure the mould (6).

After the curing time has elapsed, the hood is removed and the mould ejected from the pattern plate (7).

This process produces castings with excellent dimensional tolerance and surface finish.

Blowing or Shooting

This method of producing shell moulds is less common than that of dumping. However, the advantage is that both sides of the mould can be productive. One side of the mould is mated with one side of the second mould such that stack moulding is achieved either horizontally or vertically. The stacks are clamped for casting.

Castings particularly suited to this method tend to be small with a fairly shallow draw.

Better compaction of the moulds can be obtained by this method with no 'shadowing' as is sometimes encountered using the dumping method. The usual requirements for corebox venting to allow the air to escape are necessary.

(vii) Mould Jointing

Half moulds are normally joined together whilst still hot. Adhesives are oil based suspensions of powdered phenolic resin and hexamine which are applied to one half mould automatically or by hand. The other half mould is held in position under pressure by a pin closing mechanism or vacuum until the phenolic resin has melted and cured.

(viii) Refractory Coatings

Moulds do not usually require refractory coatings. Cores, especially the lower AFS sands, can be coated to enhance surface finish by dipping into refractory paints with special rheological properties. Cores are then dried.

(ix) Casting Performance

Surface Finish

The fine sand used for moulds generally gives excellent surface finish for all types of cast metal. However, poor sand compaction, insufficient hot strength or overbaked sand may give a poor cast surface.

Cores made from coarser sands give poor surface finish but this is often improved by use of a refractory coating.

Penetration

Penetration is not normally a problem with shell sand due to the fineness of the sand and the relatively small castings made, which do not give rise to high ferrostatic pressures.

Burn On

This seldom arises.

Mould/Metal Reaction

A mould metal reaction can occur with steels and is known as the 'orange peel defect'. This is generally eliminated by the incorporation of iron oxide to minimise exothermic oxidative reaction at the interface.

Nitrogen pinholing in steel castings was a major problem before the introduction of a nitrogen free shell sand system.

Carbon pick-up in low carbon steels is not a major problem except in thin sections.

Erosion

This is not a major problem and only occurs with poorly compacted sand.

Breakdown

Usually excellent due to the low sand to metal ratio although knock-out difficulties can be met with large solid cores.

Hot Tearing and Finning

May occur by external or internal stresses or a combination of both acting on the casting. Most of these defects may be overcome by judicious selection of shell sand containing plasticisers and optimum resin contents.

Sand Reclamation

Reclamation of shell sand is not widely practised but it has been demonstrated that thermal reclamation is necessary and once achieved gives an improved sand base.

b) Lost Foam Process

(i) Area of Application

The process is suitable for series production of aluminium castings up to about 20 kg, iron (grey, ductile and malleable) to about 50 kg and copper-based alloy castings. Because of the possibility of carbon pick-up, the process is unsuitable for most low and

medium carbon steel castings, but austenitic manganese steel and other high carbon steel castings can be made satisfactorily.

Carbon and low-alloy steel castings can be produced by using a similar process called Replicast where the moulds are held under vacuum during production and pouring.

(ii) Brief Description

Pre-forms of the parts to be cast are moulded in expanded polystyrene (or other expandable polymers) using aluminium tooling. Complex shapes can be formed by gluing EPS mouldings together. The pre-forms are assembled into a cluster around a sprue then coated with a refractory paint. The cluster is invested in dry sand in a simple moulding box and the sand compacted by vibration. Metal is poured, vaporising the EPS pre-form and replacing it to form the casting.

(iii) Special Characteristics of Lost Foam Castings

High production rates are possible. High dimensional accuracy is achieved. No cores are needed. Complex shapes can be cast. Machining can be eliminated. Minimum shotblast and grinding is needed. All sand is re-usable. Environmentally good.

Expensive tooling restricts the process to long run castings. Specialised casting equipment is needed but the capital cost is lower than for other high volume processes such as greensand. New technology must be learned. Long lead times are needed to develop new castings.

(iv) Typical applications

Grey Iron	–	valve parts, pump parts, electric motor housings, finned cylinders, engine blocks
Ductile Iron	–	pipe fittings, valve parts, manifolds, callipers
Special Alloys	–	wear resistant parts, impellers

(v) Critical Assessment

The early development of lost foam casting was handicapped by the strong patents that covered the process and the need for users to take licences from the patent holder. Only when the patents expired around 1980 was free development possible. Several major foundry groups, mainly large automotive companies, invested large resources in the process. They were looking for a way of escaping from the limitations of split-mould casting technology and of avoiding the ever-increasing capital investment needed for modern automatic greensand moulding or gravity die techniques.

The early promise of lost foam has not yet been fully realised although there are many successful applications of the process and further exploitation should be possible.

The process proved more difficult to master than had been expected and long lead times were (and still are) needed to develop each new casting. Metallurgical problems occurred with ductile iron castings, which were only overcome by the development of new foam pattern materials (see below for details). These problems have been overcome by the development of new foam pattern materials, the latest of which has only recently become available. Metallurgical problems also arose with aluminium castings, making critical castings such as high performance cylinder heads difficult to make by the process.

Nevertheless, for the right application the process offers significant advantages over all other casting methods, and its use is steadily growing as the most suitable applications are found. However, it seems unlikely to achieve more than a specialist position, not unlike shell moulding, in the range of casting processes available.

The best applications are those where the precision of the process enables machining to be eliminated, such as valve parts and pipe fittings, or where complex shapes not possible by other casting processes can be made using the ability to glue pre-forms together.

(vi) Details of the Process

Moulding of the Pre-Form

See Exhibit BE.

A foam pre-form is needed for every casting. Pre-forms are moulded on special machines similar in size and complexity to automatic core blowers. The sequence of operation is as follows:

- a) Purchase raw bead from a chemical supplier. The bead consists of spherical beads of polystyrene (or other polymer) of carefully graded size. The bead is impregnated by the manufacturer with a blowing agent, usually 5–7% of pentane. Bead is supplied in drums and has a shelf life of 3–6 months, but only 6–8 weeks once the drum has been opened, since the pentane slowly leaks away.
- b) Pre-expand the bead to the required density, usually 20–24 grams/litre by steam heating to above 100°C in a batch-type pre-expander. Casting quality is affected by pre-form density, which must be carefully controlled.

- c) Age the pre-expanded bead for at least 4 hours to equalise the pressure inside and out of the bead.
- d) Mould the pre-form in a moulding press using a hollow-backed aluminium die. The pre-expanded bead is blown into the closed die (which is vented like a corebox). The die is steam-heated, causing the beads to expand further and fuse together. After fusing, the die is cooled with water sprays (often with vacuum assistance) so that the pre-form is cooled sufficiently to be ejected with distortion – Exhibit BF.

Automatic machines are used with a cycle time of 1.5 to 2 minutes, depending on section thickness of the pre-form. While the moulding time is relatively long, the moulding machines are large with pattern plates typically 800 x 600 mm, 1000 x 700 mm or larger, so that multiple impression dies are frequently used to keep the cost of the pre-forms low.

- e) After moulding, the pre-form is stabilised by storing for at least 5 days during which a small contraction (around 0.5%) occurs. The contraction, plus the expected casting contraction must be allowed for in the die dimensions. Accelerated contraction is possible by storing pre-forms in a chamber kept at around 60°C, but there is some loss of dimensional precision when stabilisation is accelerated.

The technology of moulding pre-forms is not easy and many foundries prefer to purchase from a specialist supplier rather than make their own.

Where possible, pre-forms are moulded in one piece using draw-backs on the aluminium dies to form hollow cavities. Many components such as manifolds, must be moulded in 2 or more parts, which are then glued or welded together.

Hot melt adhesives are usually used, applied by automatic glue printers to ensure precision. Thermal welding of foam parts is also possible using special machines, but care must be taken to avoid local shrinkage of the pre-form.

Assembling Clusters

Large pre-forms may be cast singly, but more often pre-forms are assembled into clusters for coating and casting. The most common type of cluster is an assembly of pre-forms around a central down sprue. This makes a compact and rigid cluster which is easy to handle manually or mechanically for coating and placing in moulding boxes.

Cluster design is one of the most difficult aspects of the lost foam process. The pre-forms must be orientated in such a way that they will fill completely with sand by

vibration alone. The pre-forms are attached to the sprue by the ingates. The ingates therefore serve a dual purpose, firstly of holding the pre-form rigidly so that it does not distort during dipping in the coating and during sand filling. Secondly, the ingates control the metal flow during casting. It is not easy to achieve both functions efficiently and experimentation is usually needed before a successful design is achieved. In some cases the pre-forms are dip-coated individually and assembled into clusters after the coating has been dried. Special handling fixtures may be used to support clusters during coating and sand fill.

Coating the Pre-Form

The refractory coating plays a critical role in the casting process. If no coating is used, sand burn-on occurs and severe sand erosion is probable, particularly near ingates. The dried coating must be permeable to allow the gaseous and liquid products of pre-form thermal degradation to escape from the mould. The permeability of the coating controls to a large degree the rate at which the casting fills.

Suppliers have developed special water-based coatings for the lost foam process. The coated pre-forms are dried in a low temperature oven with good air circulation. Complex hollow pre-forms such as manifolds and cylinder blocks are difficult to dry internally and dehumidifying ovens may be used or even microwave ovens, but preliminary air drying is necessary before microwave drying.

Vibrating the Sand

The coated and dried pre-form cluster is placed in a moulding box, either manually or mechanically. The boxes may be round or square, they are made of sheet steel with reinforcement to prevent movement during vibration. Typical sizes are 800 mm diameter x 900 mm deep or 900 x 900 x 900 mm. The depth is necessary because the top of the pre-forms must be covered with about 300 mm of sand.

Dry silica sand, usually AFS 40–55 is poured evenly around the cluster, a perforated distributor plate is often used to spread the sand uniformly, with a shield to prevent direct impact of the sand on the fragile cluster. As the box is filled, it is vibrated to compact the sand and cause it to flow into the cavities of the pre-form. Vibration is critical, excessive acceleration forces may distort the pre-forms while if compaction is incomplete, metal penetration causing sand burn-on may occur when metal is poured.

Special vibration tables are available, ranging from simple single axis vibration with manual frequency control to multi-axis tables with computer control so that frequency is varied automatically as the moulding box is filled with sand. It is not possible to cause

sand to flow uphill by vibration so pre-forms must be orientated in such a way that cavities may be filled horizontally or downwards.

Casting

See Exhibit BG.

When iron is cast into EPS pre-forms, the high temperature and heat content causes the EPS to be pyrolysed more rapidly than with aluminium. The gas evolution is greater, particularly from thick section pre-forms. It is usual to use a long (600 mm), hollow, fibrous refractory pouring cup and sprue terminating in an EPS sprue base to which the pre-form cluster is attached. This permits very rapid filling of the cluster and casting times are similar to those of empty moulds. It is essential that the liquid metal fills the casting as fast as the thermal degradation and vaporisation of the pre-form permits so that a gap never forms between metal and pre-form. Any hesitation in pouring is likely to result in partial mould collapse.

It is common to assist the smooth removal of gases from the pre-form by applying a vacuum to the base of the moulding box during pouring. If vacuum is not used, the sand must have very high permeability. This can be achieved by using a coarse grade sand, AFS 35–40. No smoke or fume is released into the foundry, all the products of pyrolysis of the pre-form pass into the sand.

Demoulding

When the castings have cooled, they are demoulded by tipping the moulding box and its contents onto a grid. Fume is emitted at this stage, the vapours are combustible and are frequently deliberately ignited to burn the polystyrene residues. Aluminium castings are usually washed with water to remove residual coating. Iron castings are shotblasted. The casting is an exact replica of the pre-form, every detail of the pre-form is reproduced with astonishing detail. If the pre-form has been badly moulded, the casting will reproduce the 'bead trace' of the moulding so that lost foam castings can often be recognised by their appearance (unless they have been heavily shotblasted). If the pre-form has been well made and assembled, there is no grinding or finishing needed apart from removing ingates.

The moulding sand is screened, cooled and air classified for re-use. If aluminium is cast, the polystyrene residues are not completely burnt at the low casting temperature and it is necessary to replace a small proportion of the used sand with new or thermally reclaimed sand to prevent build-up of styrene and other organic material. In ferrous

foundries the polystyrene residues are more completely burnt and new sand addition is not needed.

(vii) Casting Characteristics

Lost foam castings are characterised by high dimensional accuracy, good surface finish, elimination of joint line flash and exceptional reproduction of detail. They may also suffer defects characteristic of the process, as well as some conventional casting defects.

Iron Castings

Residues from the incomplete vaporisation of EPS can cause surface defects on iron castings. The defect is a form of lustrous carbon defect and is characterised by wrinkling or pitting of the upper surface of thick sections of the casting. High carbon irons, such as ductile iron, are most prone to the defect. The defect can be eliminated by using alternative polymers for the pre-forms. PMMA (polymethylmethacrylate) depolymerises completely to gaseous monomer and leaves no residues in the casting. PMMA is not easy to mould into pre-forms with good surface finish but expandable beads of a co-polymer of EPS and PMMA have been developed which eliminate lustrous carbon on all but the heaviest section castings and are easier to mould than 100% PMMA.

Conventional casting defects can also occur, the most common being slag defects since it is not easy to use conventional slag traps with lost foam. It is essential therefore to take extra care to ensure clean melting and ladle practice. Metal filters can be used, they are usually fitted into the base of the pouring cup.

White iron castings such as malleable and wear resistant iron castings do not suffer from lustrous carbon defects because carbonaceous EPS residues are able to dissolve in the low carbon liquid metal.

Steel Castings

Steel castings made by lost foam are prone to carbon pick-up from the pre-form. It is not possible to guarantee uniform carbon pick-up and randomly distributed areas of high carbon may occur, probably where globules of EPS residue have been surrounded by liquid steel and been unable to diffuse away before solidification. For this reason, the use of lost foam is restricted to a few high carbon steels such as austenitic manganese steel.

(viii) Size of Casting Possible

The size is limited to some extent by the size of the moulding machine on which the patterns are made, pattern plates larger than 1000 x 700 mm are uncommon. Larger pre-forms can be made by gluing sections together. The size of the moulding box is a further limitation, so the largest castings made in practice are about 800 x 600 x 600 mm.

(ix) Dimensional Accuracy

Lost foam castings are characterised by high dimensional accuracy because of the precise tolerances that can be achieved in moulded pre-forms. Machine tools are precisely machined from stable wrought aluminium billet.

Moulding temperature is no higher than 100°C so that tools are not subjected to severe thermal cycling like pressure die-casting dies. Little tool wear occurs in use because the EPS bead is soft and non-abrasive. The dimensional tolerances that can be achieved as pre-forms are shown in Figure 51.

Casting tolerances are normally about twice the pre-form tolerances due to factors such as:

- distortion of the pre-form during coating and sand filling
- variation in metal temperatures and composition
- internal stresses arising during freezing and cooling of the casting.

(x) Special Advantages of Lost Foam Castings

Tool life is long (up to 250,000 cycles) so that tool cost becomes low for high volume parts. Cast-to-size is possible in many cases, eg to form bolt holes in flanges. Reduced casting weight is often possible because section thicknesses (for example of manifold pipes) can be accurately maintained.

Reduced grinding because there is no flash.

Reduced machining of the casting. In many cases, machining can be completely eliminated.

Possibility of combining two or more castings into one by gluing pre-forms together.

High production rates are possible because clusters consisting of many pre-forms can be cast.

The process is environmentally good and all sand is re-usable.

(xi) Special Difficulties of Lost Foam Castings

Metal tooling is essential so the tooling cost restricts the process to long run castings.

Specialised equipment is needed, so considerable capital investment is necessary (though less than for an automated greensand plant of the same capacity). New technology has to be learnt; a foundry adopting lost foam must expect to spend many months learning how to design effective clusters for efficient casting.

Long lead times are needed to develop new castings. If complex shaped castings are made, it is difficult to predict pre-form and casting contractions precisely so that tool adjustments may be needed.

(xii) Casting Costs

Capital Costs

Specialised casting plant is needed for the process.

The very minimum needed is moulding boxes, vibration tables, sand fill hopper, track for box movement, box tipping mechanism, sand screening, cooling return elevator, with dust and fume extraction and possibly vacuum pump and manifold. Coating dip tank and warm air drying area are also needed.

For high volume casting, pattern assembly, coating and drying are usually mechanised. Box filling, vibration, vacuum connection and box movement are also mechanised. The cost of a fully automatic plant is around 50% of an automatic greensand plant of the same capacity.

Pre-form manufacture requires substantial capital investment but many foundries purchase pre-forms from specialist suppliers.

Tooling Cost

This includes moulding dies, glue fixtures and printers and dimensional checking fixtures for pre-forms and castings.

The cost is comparable with but usually lower than the equivalent metal patterns and coreboxes used for high volume greensand. It is considerably lower than gravity die costs. A major advantage of lost foam tooling is the long life and low maintenance compared with tooling used for sand moulding.

Materials

If pre-forms are purchased from an outside supplier, they represent a major cost, possibly between 10–20% of the total cost of the finished casting. If the foundry makes its own pre-forms the material cost is low.

Other materials used are special coatings and pouring cups.

Labour

There is manual labour involved with the manufacture of pre-forms and the assembly of clusters. Overall the labour content is comparable with an automated greensand plant making highly cored castings.

Finishing

Shotblasting and grinding are much less than for other processes.

Overall Costs

Lost foam costs compare well with automated greensand and gravity die casting but at the present stage of development there is the additional cost of learning the new technology and developing casting methods for each new casting that is made. Equipment and consumable suppliers can provide a certain amount of process know-how, but foundries adopting lost foam must expect to invest time and money before the process is mastered.

(xiii) Environmental Factors

Health and Hygiene

There are few health problems with the materials used in the process. EPS and the other expandable beads used for pre-forms are safe and pleasant materials to handle. There is a fire risk in the pre-form manufacture due to the pentane gas released from the bead in its raw state and during pre-expansion. Good ventilation and elimination of

smoking and naked flames are needed. The hot-melt glues used emit slight fume, but normal ventilation in the gluing area is sufficient to prevent problems.

The coatings are water-based and cause no problems during application and drying.

Environment

Dust may arise during sand filling, but if the sand treatment plant has been correctly designed, all fines should be removed before the sand is re-used. Local ventilation is usually provided at the sand-fill station.

When correctly practised, no smoke or fume is released into the foundry atmosphere during casting. All the pyrolysis products from the pre-form pass into the sand.

Smoke and fume is released at the shake-out and is frequently ignited. The normal extraction provided at any sand shake-out station is suitable.

The fume from the shake-out, the exhaust from the vacuum pumps (if vacuum is applied during casting) and from the sand cooling plant contains pyrolysis products from the polystyrene or PMMA of the patterns including CO, CO₂, CH₄, styrene and heavy organic vapours arising from the breakdown of polystyrene, etc. In most lost foam foundries, these materials are released into the outside atmosphere after dilution with the rest of the exhaust air from the foundry. Of the exhaust fumes, styrene has the most distinctive odour and is recognisable at very low concentrations.

At the high pouring temperatures of ferrous foundries, most of the styrene burns during casting or at shake-out so that the exhaust fume has little odour. In aluminium foundries, the sand temperature is low enough for liquid styrene to condense on the sand. If the sand is returned to the foundry without treatment, the odour may be troublesome, but if it is correctly cooled before re-use, most of the styrene is vaporised and carried away with the exhaust air from the cooler. At the present time most lost foam foundries take no special precautions to treat the exhaust air.

Reclamation

All the sand is recovered and re-used. In ferrous foundries, most of the EPS residues are burnt during casting and shake-out leaving only a small amount of carbon residue on the sand. The sand is cooled and classified to remove dust and all is returned for re-use. In aluminium foundries, the sand temperature is not sufficient to burn the residues and the sand may become coated with a tarry residue which eventually reduces the flowability.

This residue may also be harmful if ingested by operators. Large aluminium foundries often remove a proportion (5-10%) of the sand and either thermally reclaim it or replace it with new sand.

Waste Disposal

Excess sand which has not been thermally reclaimed may be coated with organic chemicals arising from the degradation of the pre-forms. The composition of these organics has not been identified, but must be assumed to be potentially harmful, as with any resin based foundry waste. It must be disposed of at an approved site.

General

Lost foam foundries are clean and fume-free and there is little material to dispose of compared with other sand processes.

(xiv) Applications

Lost foam foundries usually look for applications where the process allows a higher added value casting to be compared with conventional processes. This usually means saving machining by casting to size or by combining two or more castings into one. For example:

- Valve bodies (and other valve parts), pipe fittings, pump bodies, etc, can be cast to size.
- Turbo charger bodies and elbows can be cast in one piece.
- 2-stroke engine cylinders can be cast with precise valve ports.
- Electric motor housings are cast with thinner fins and wall sections, giving weight savings.
- Wear-resistant components are cast with machining reduced or eliminated.

(xv) Use of the Process and Future Potential

There are between at least 50 and 100 major foundries using the process. These include:

- major automotive foundries (ferrous and non-ferrous)
- ductile iron pipe-fitting manufacturers
- valve manufacturers (grey and ductile iron)

- pump manufacturers
- general engineering foundries
- wear-resistant iron foundries
- electric motor manufacturers

The number of foundries using lost foam is steadily growing as new applications are found.

Other castings which may move to lost foam in the future are:

- 4-stroke engine blocks
- cylinder heads
- differential cases
- brake callipers.

However, lost foam casting is unlikely to displace greensand as the major process for iron casting or die casting for aluminium. As with other specialised processes, it is likely to be accepted as the right process for certain castings. It seems likely that the lost foam process will find a place in foundry technology similar to that occupied by shell moulding.

c) Centrifugal (Permanent Mould)

This is used to produce hollow products, such as large iron water pipes, domestic rainwater downpipes and steel mill rolls. The principle is the same for each, in that molten metal is introduced into a mould cavity that is spinning around its axis and centrifugal force causes the metal to move to the outside of the mould.

Centrifugal casting was developed to overcome the limitations of static casting for cylindrical shapes, both solid and hollow. It produces a more uniform product and close control of the solidification conditions can be achieved. This results in a more uniform hardness, better chill depth, finer grain microstructure and higher mechanical properties.

(I) Horizontal Centrifugal Casting

Pipes and cylinder liners, etc, are cast in permanent moulds which are spinning on the horizontal axis. The moulds are usually coated or lined with a refractory-based material to extend their life. A measured quantity of metal is poured in and flows to the outside of the mould, where it solidifies against the mould wall, which is often water or air cooled. Slag or other inclusions, being of lower density, accumulate at the centre of internal diameter. They can be removed later during boring. With pipes, the mould is

rotating at a slight declination, so that slag accumulates at one end and this section can be cut off.

The machine consists of a series of large rollers equipped with a variable speed drive. Moulds are often coated separately, but can be coated on the machine using a retractable spray nozzle. Moulds are required of the correct length and internal diameter, with appropriate machining allowances, to produce the correct external diameter for the product.

(ii) Vertical Centrifugal Casting

Rolls of steel rolling mills are often cast in a vertical centrifugal casting machine. The machine consists of a turntable unit equipped to carry the necessary load variation during the casting cycle and with a variable speed drive electric motor. Radial mould location is carried out by a support roller system designed to accommodate a range of barrel diameters. Lengths can be altered by raising or lowering the radial support system and by using different mould sizes.

Moulds for vertical centrifugal casting are normally made up in sections and bolted together. Again, a refractory wash is applied to extend mould life.

Due to the combination of high rotational speeds, heavy moulds and high metal weights, a high degree of safety is essential. This is achieved generally by having the main construction encased in a thick concrete enclosure. Out-of-balance forces cannot be tolerated while spinning and therefore the mould is spun before pouring commences to ensure it is in dynamic balance.

Metal is introduced from the top and falls to the bottom, where forces acting on the liquid metal cause it to rise up the mould wall. This process can be used to cast dual metal rolls, the harder shell metal being cast first, with a different metal for the solid core. As the second metal is added it mixes with the shell metal and a narrow mixed zone occurs at the interface. During the second pour, rotational speed is gradually reduced until the mould becomes static. Final feed metal can then be added.

Rotational speed changes, together with the time delay between pouring the shell and the core metal, are critical, as is the speed of pouring as the metal climbs up the rotating mould under the influence of centrifugal forces.

Developments are continuing to improve the product life – for example by introducing different alloy materials for the shell metal which is the working surface of steel mill rolls.

d) V-Process

The moulding medium is clean, dry, unbonded silica sand, which is consolidated through the application of a vacuum or negative pressure to the body of the sand. The patterns must be mounted on plates or boards and each board is perforated with vent holes connected to a vacuum chamber behind the board. A pre-heated sheet of highly flexible plastic material is draped over the pattern and board. When the vacuum is applied, the sheet clings closely to the pattern contours. Each part of the moulding box is furnished with its own vacuum chamber connected to a series of hollow perforated flask bars. The pattern is stripped from the mould and the two halves assembled and cast under vacuum.

1) Method of Operation

The manufacturing stages of the V-Process are described and illustrated in Exhibit B1. This moulding process is based on generating a vacuum when a thermo-plastic contour foil is deep drawn over an appropriately prepared pattern, in order to maintain the mould shape in sand without binding material, right through the stages of pouring, cooling and emptying.

Heated plastic foil is drawn using vacuum over a pattern provided with a series of apertures and mounted on a closed box from which the air can be evacuated (Nos 1 and 2).

The moulding box is placed onto the vacuum box with the pattern in position (No 3).

Fine grained, quartz sand free of binding material is filled into the mould and compacted by vibration (No 4).

After applying the foil cover, air is extracted from the sand so that the mould becomes firm. To release the mould, the vacuum is replaced by a small amount of pressure (Nos 5 and 6).

During and after pouring, the mould remains connected to the vacuum system (No 7).

Only when the mould is to be knocked-out is the vacuum released. The sand and the casting fall free of the moulding box. No additional force is required (No 8).

Exhibit Z Major moulding processes

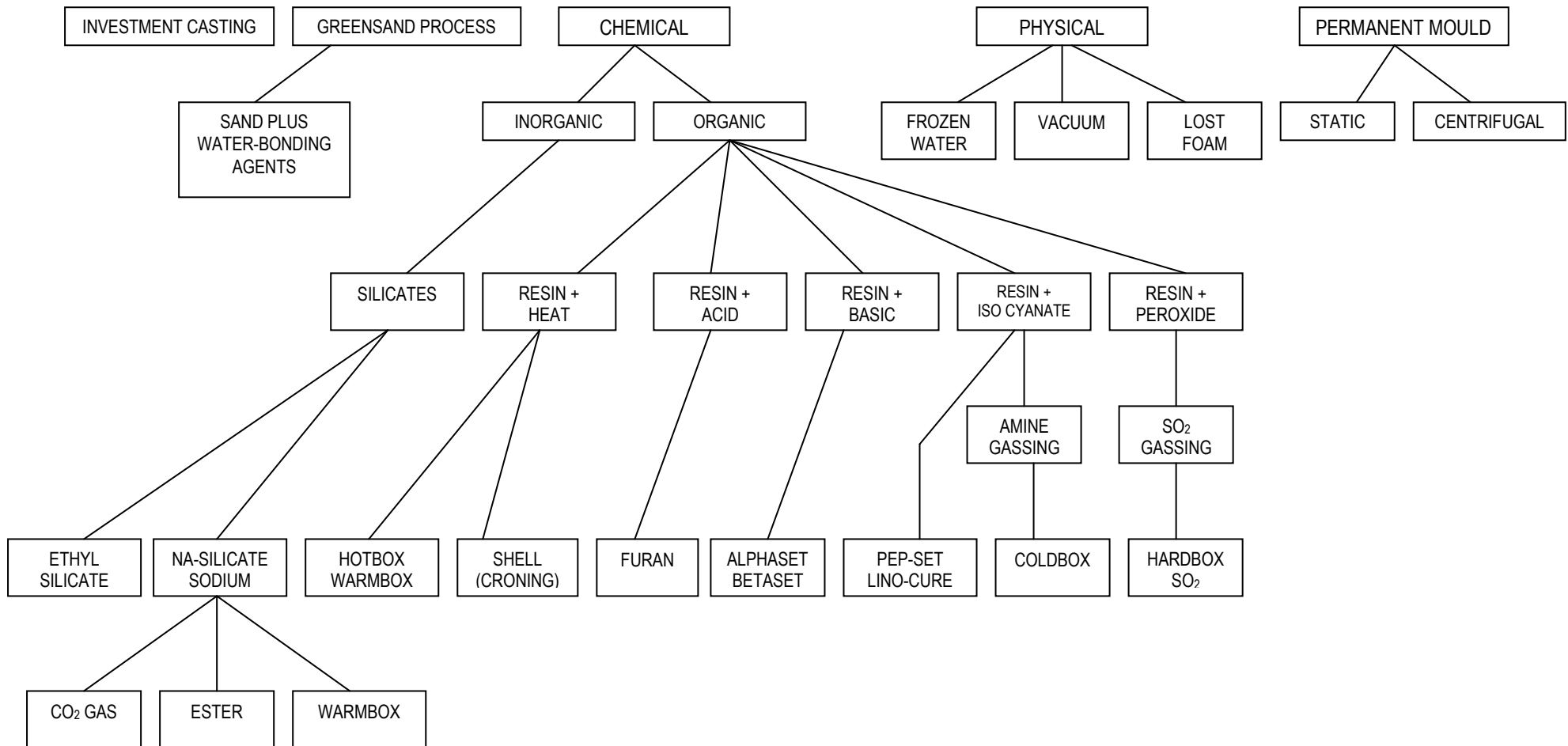


Exhibit AA Casting process comparison – dimensional tolerances

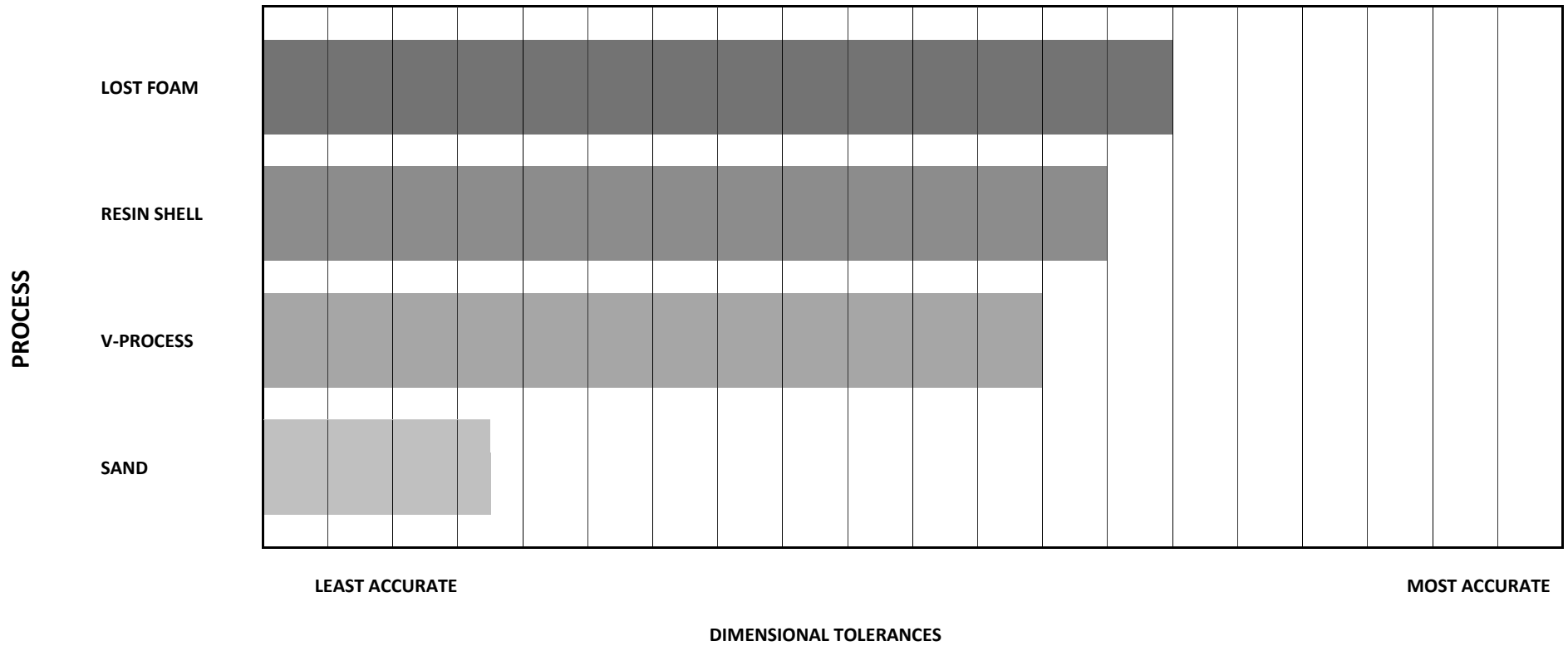


Exhibit AB Casting process comparison – relative surface finish

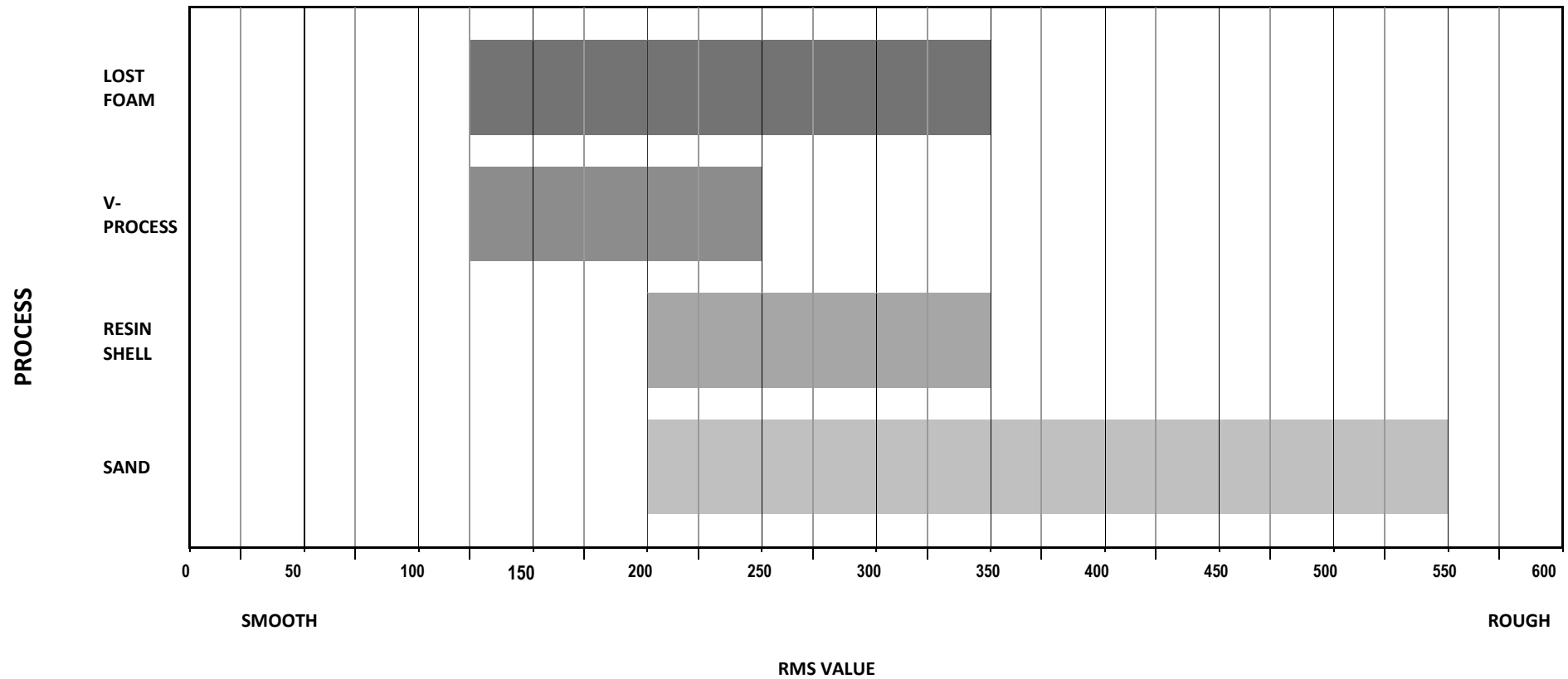
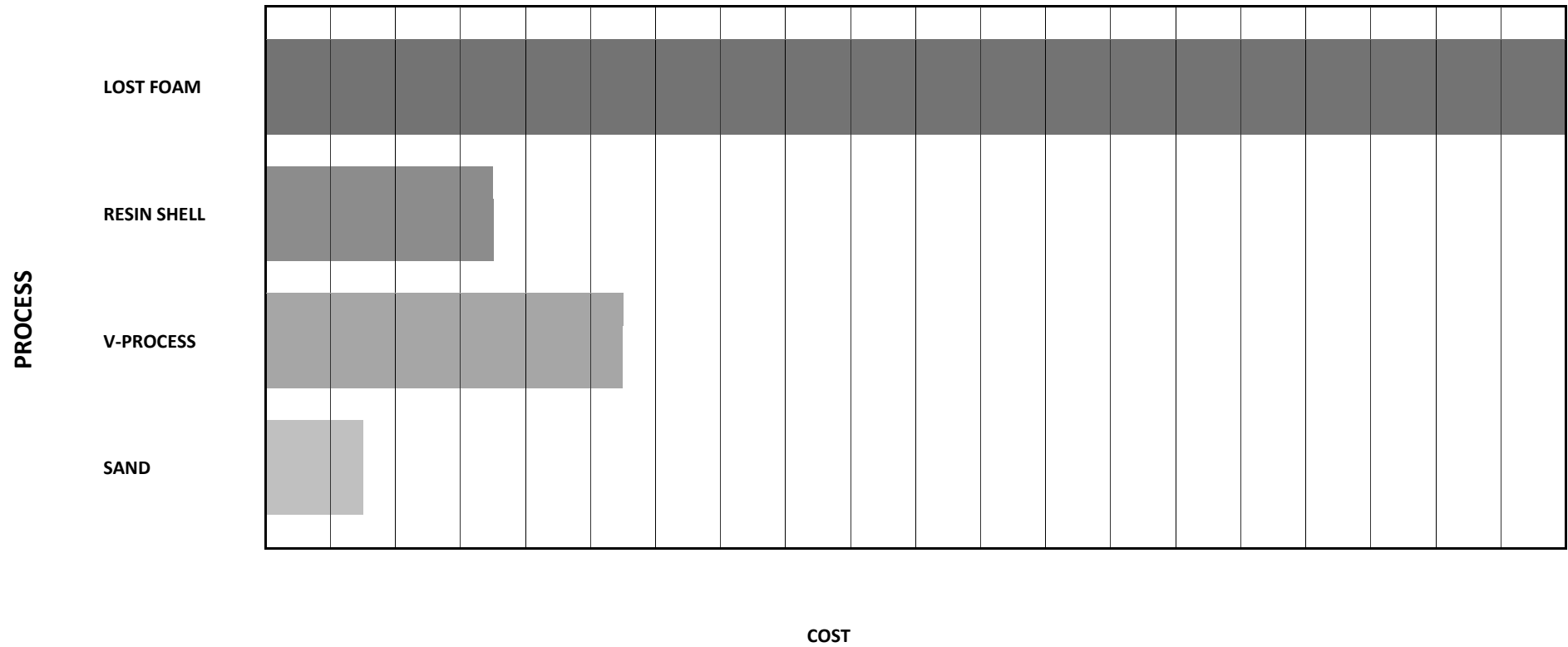


Exhibit AC **Casting process comparison – tool costs**



Casting process comparison – complexity of design



Exhibit AE Casting process comparison – ease of engineering changes



Exhibit AF Casting process comparison – near net shape capability

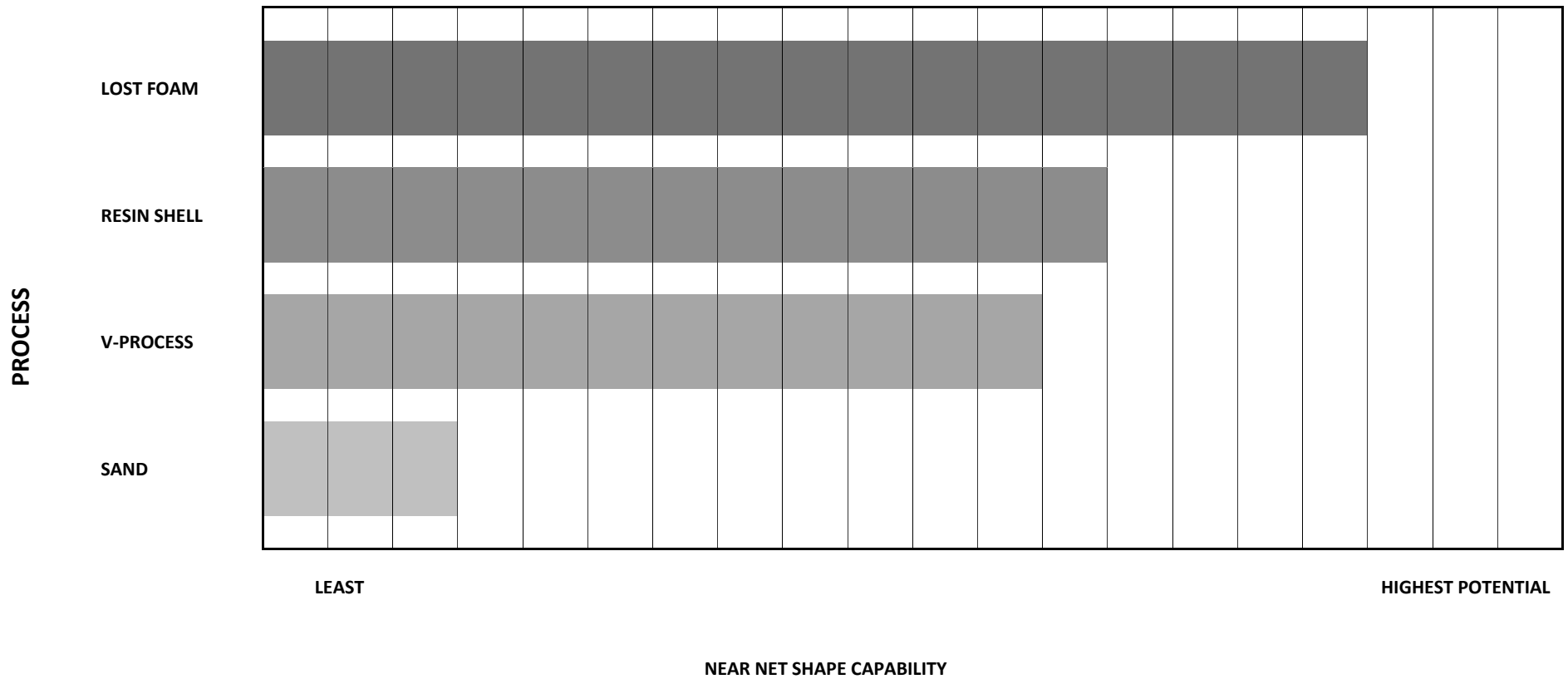


Exhibit AG

Classification of grain shapes

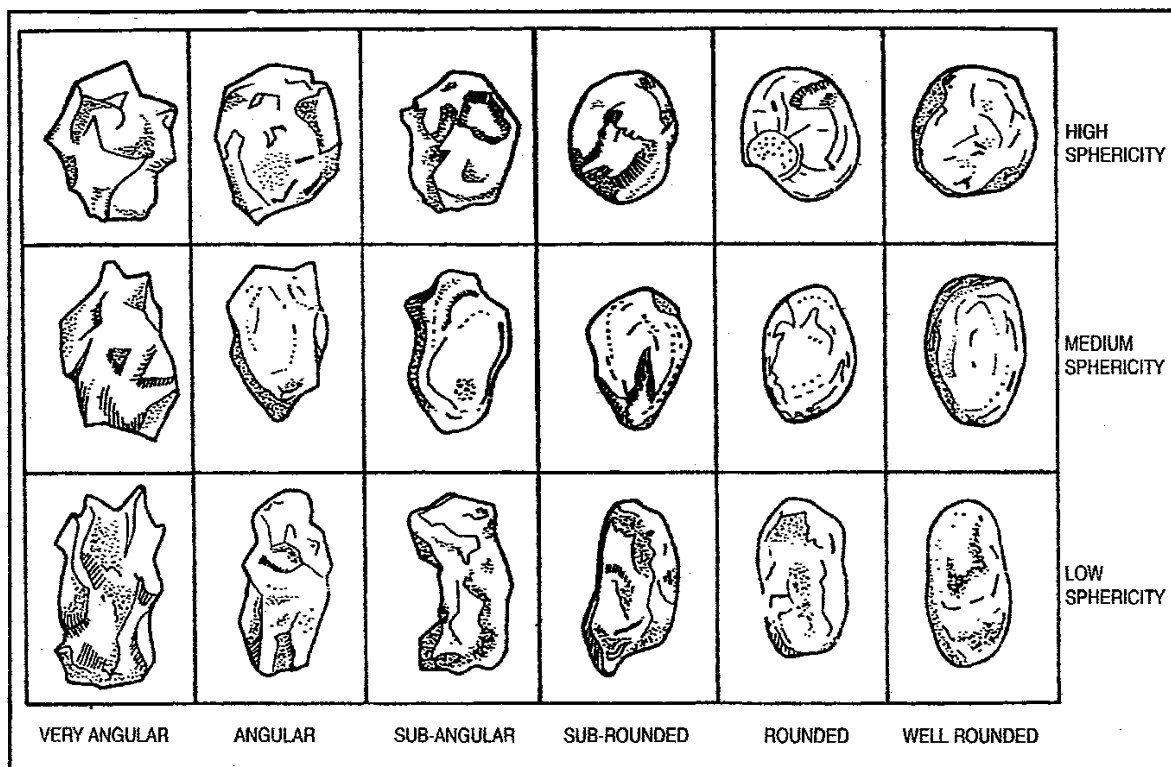


Exhibit AH Sintering points for silica sands

Sand	Sintering Point (°C)
High purity silica sand (>99% quartz)	1450
Medium purity silica sand (96% quartz)	1250
Sea sand (high shell content)	1200
Natural clay bonded sands	1050–1150

Exhibit AI

Simplified clay structure

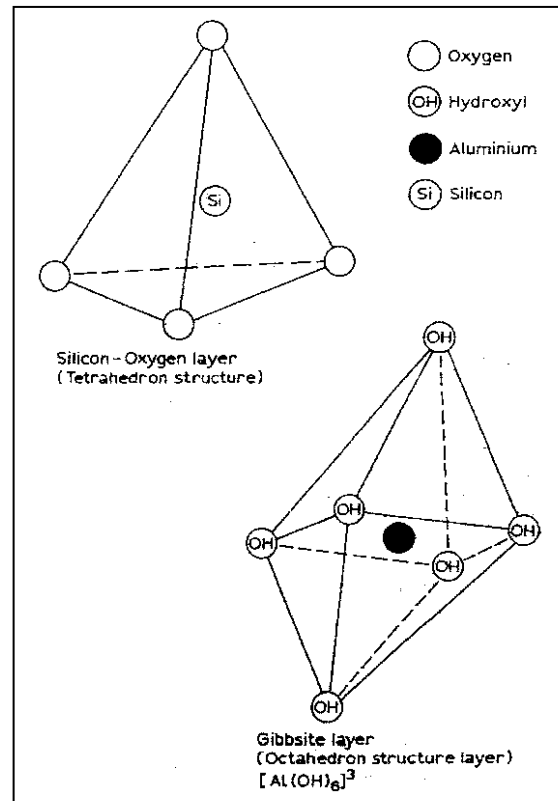


Exhibit AJ

Montmorillonite

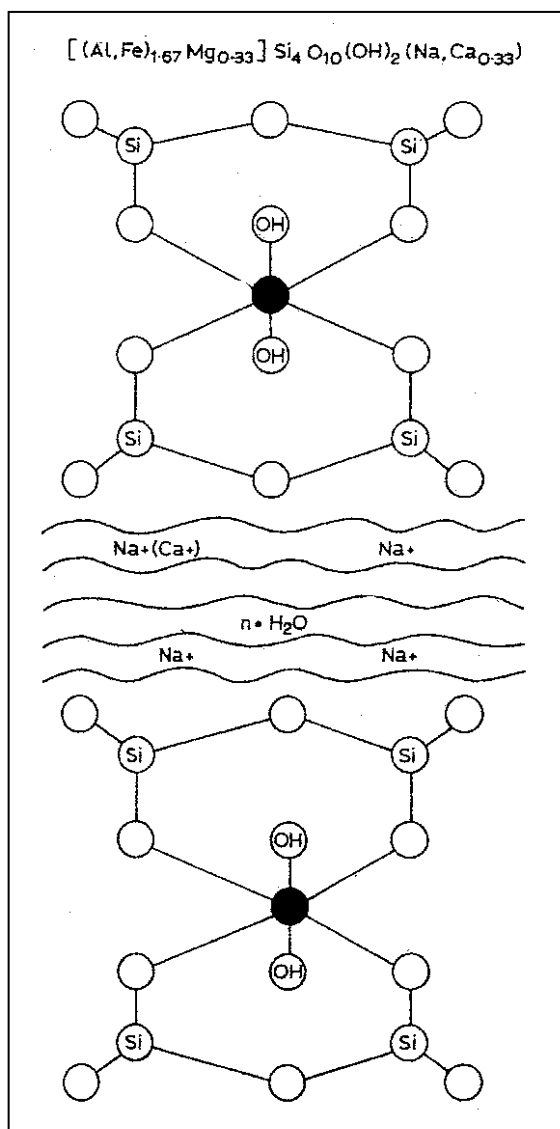


Exhibit AK

Kaolinite

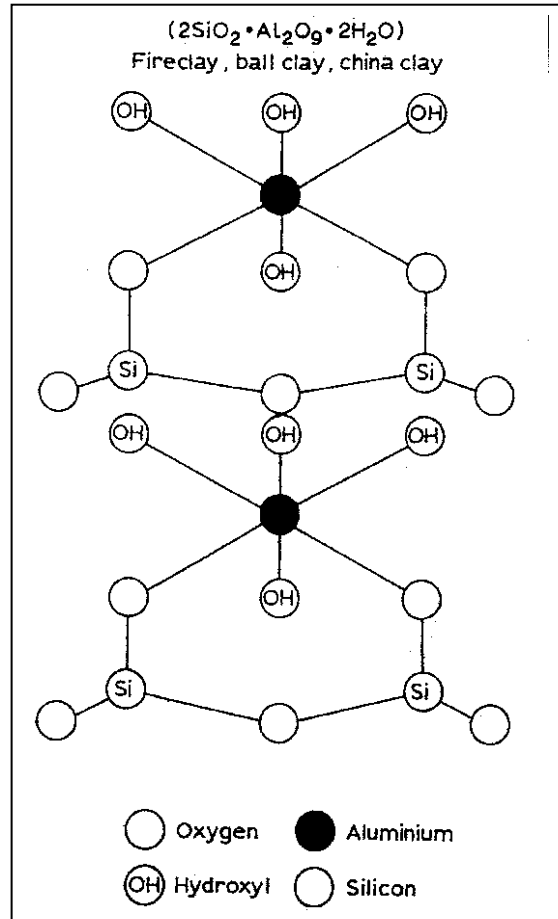


Exhibit AL

Vertical wheel batch muller

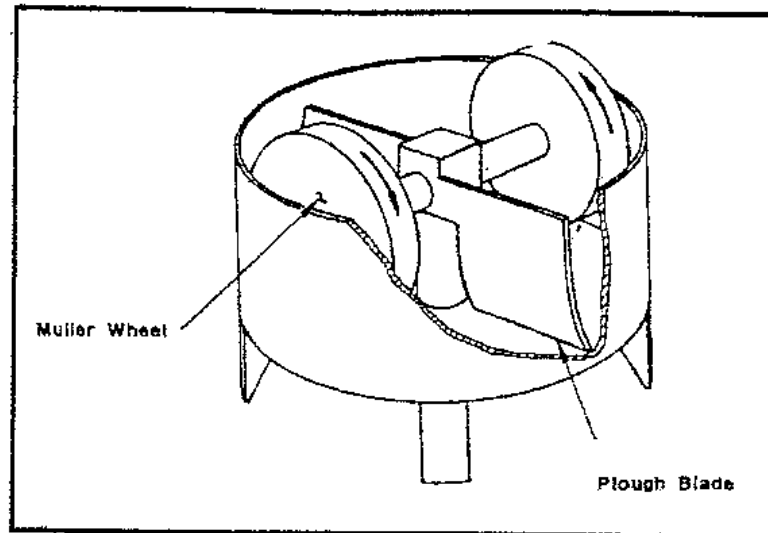


Exhibit AM

High speed muller

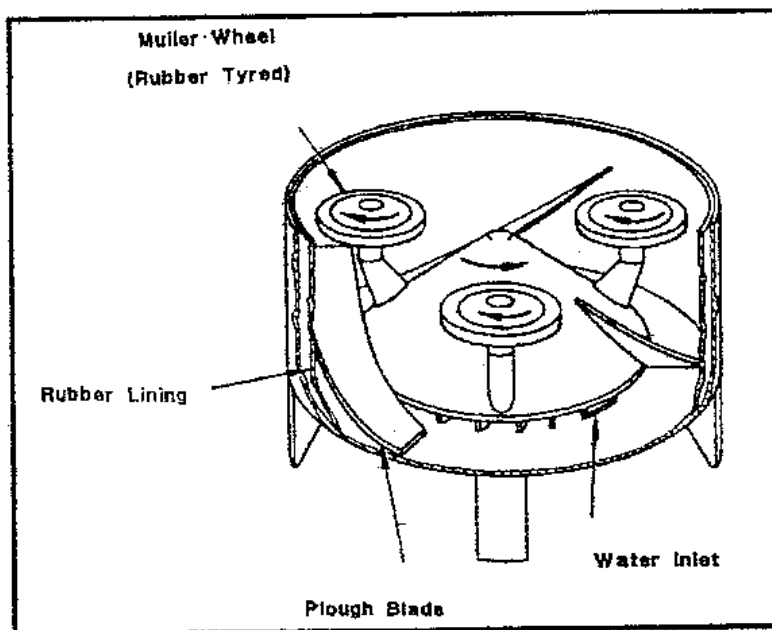


Exhibit AN

Continuous mixer

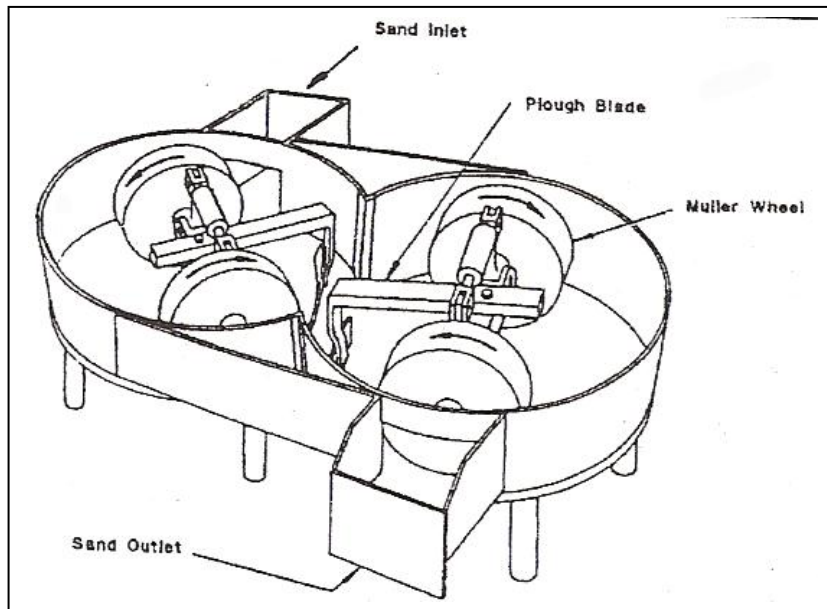


Exhibit AO

Alteration to bulk density of foundry sand with mixing intensity

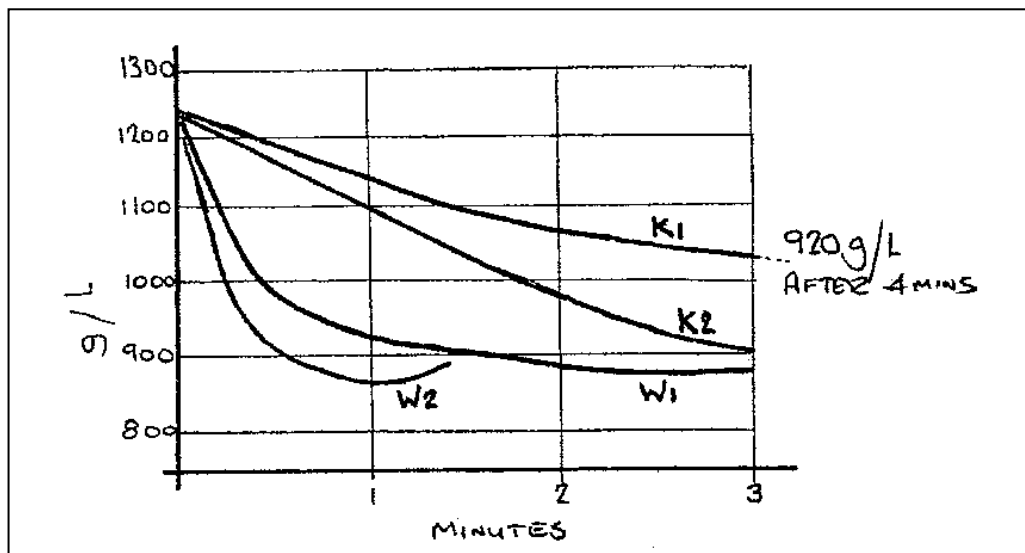


Exhibit AP

Comparison of mixing times

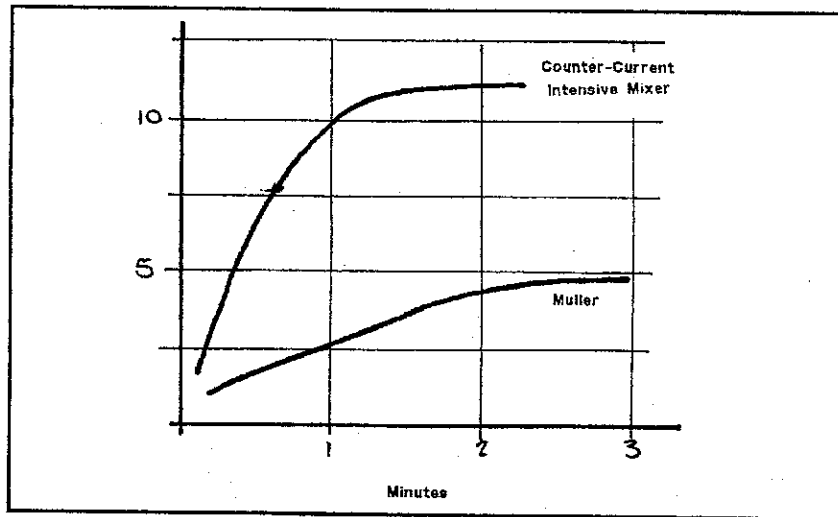


Exhibit AQ

Jolt-squeeze method

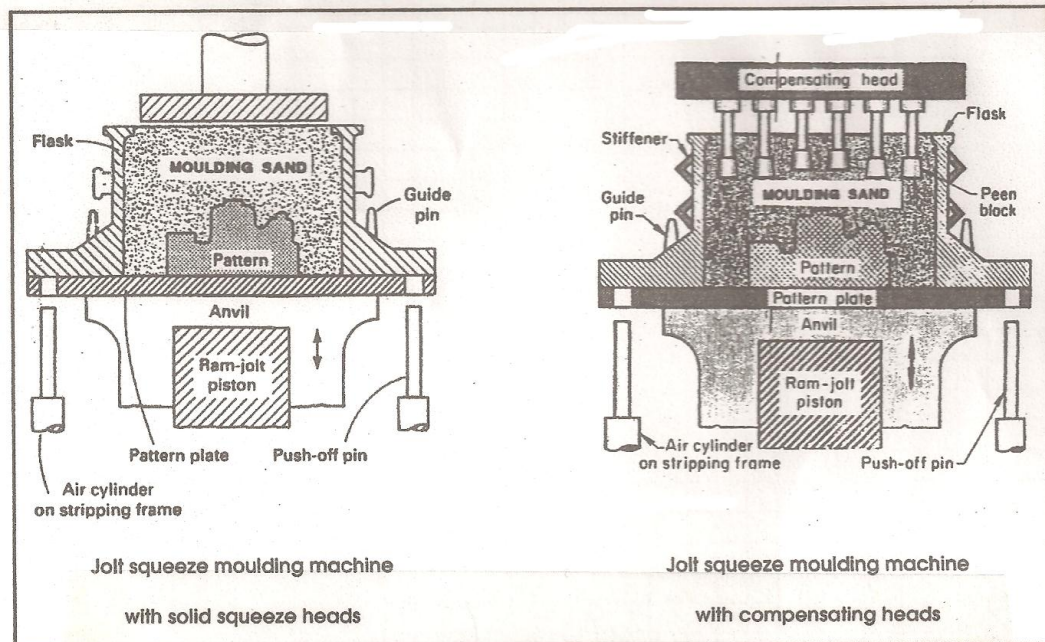


Exhibit AR

Impulse and squeeze compaction operating sequence

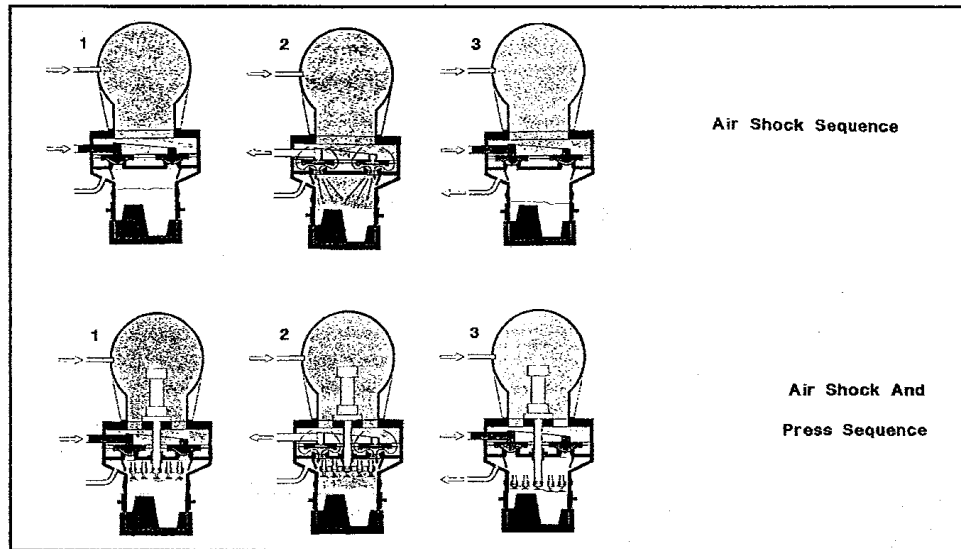


Exhibit AS The Seietsu process sequence

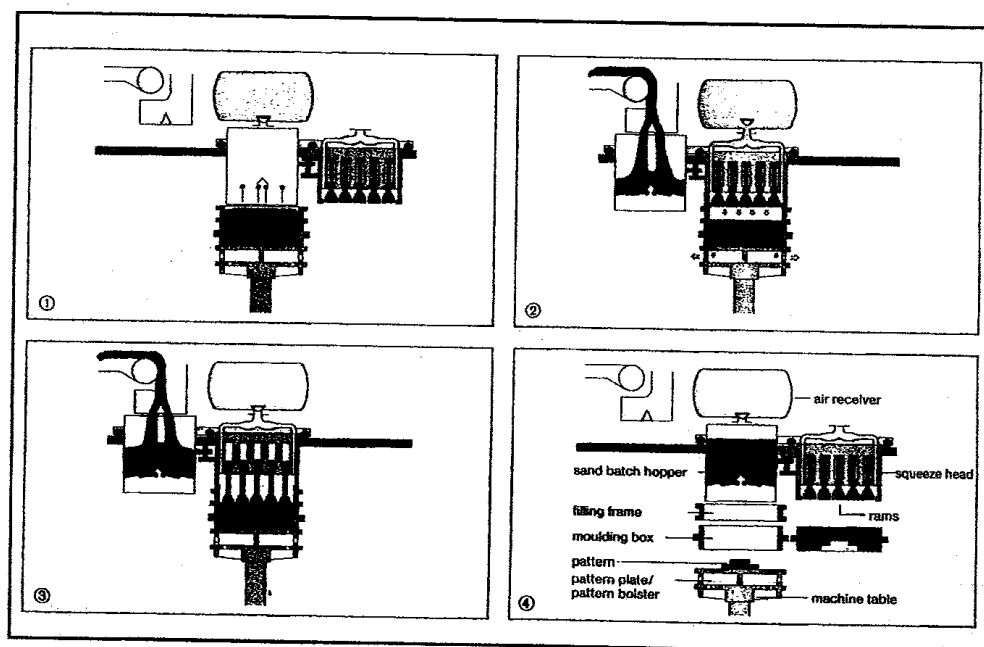


Exhibit AT

The Dynapuls operation

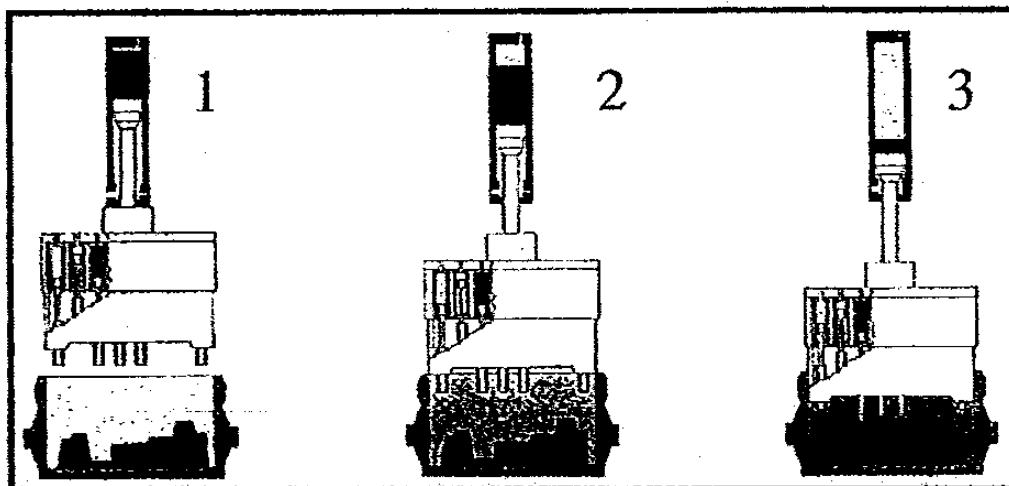


Exhibit AU

Variable compacting intensity

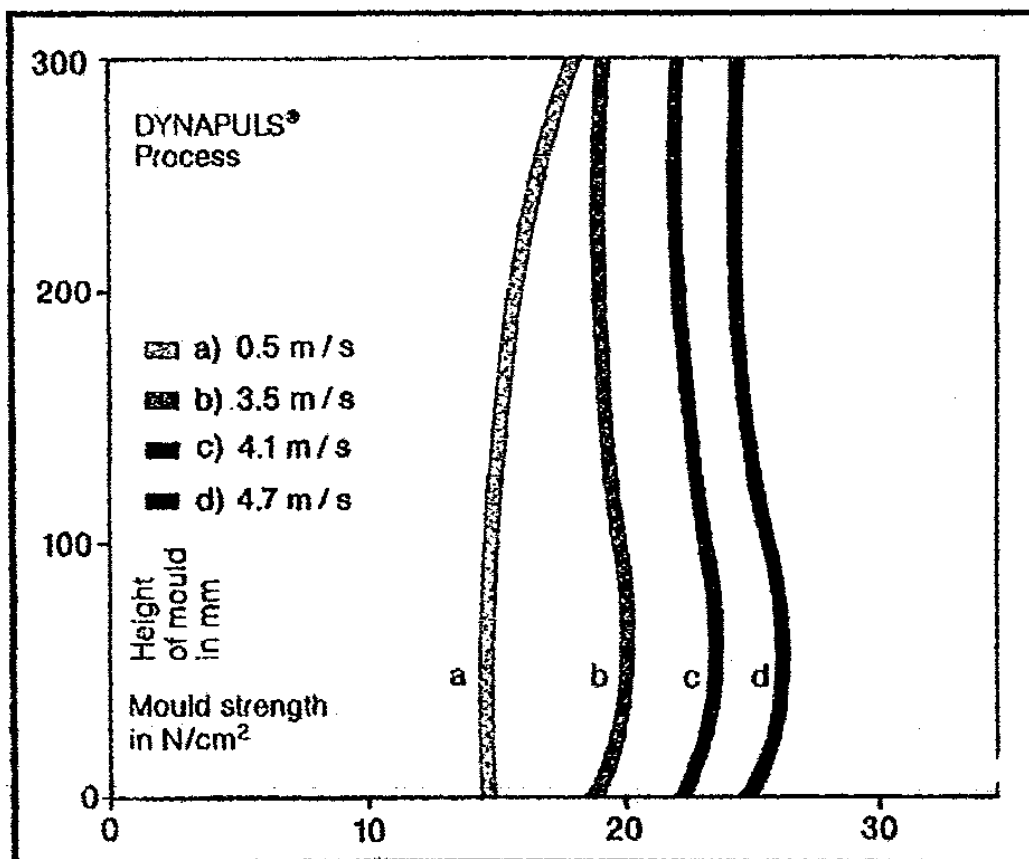


Exhibit AV Vacuum squeeze moulding

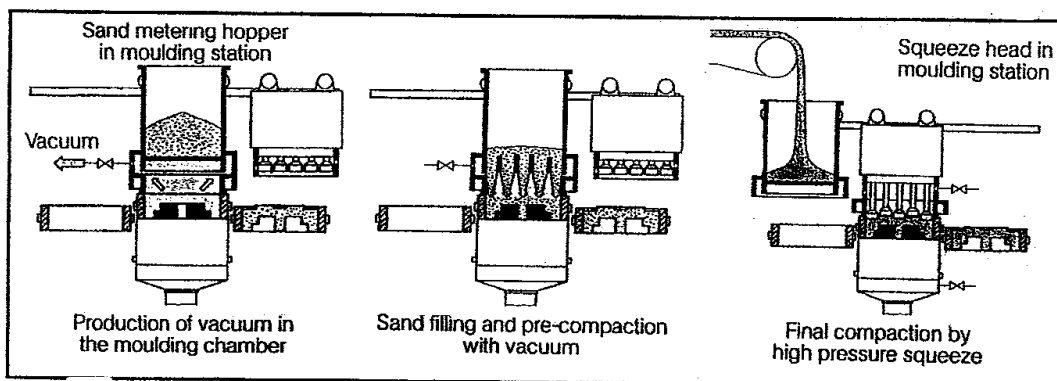


Exhibit AW Hunter machine sequence

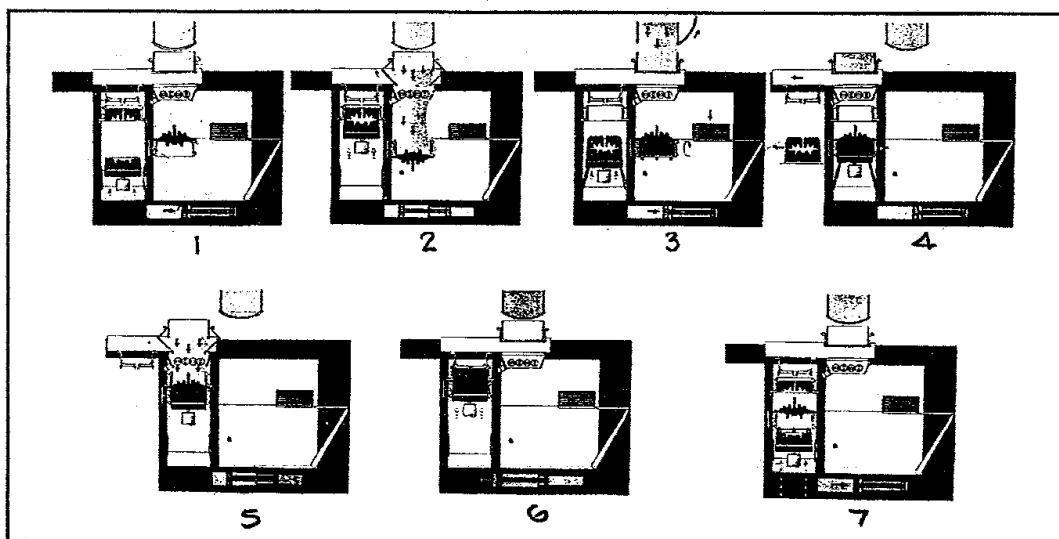


Exhibit AX Vertically parted flaskless moulding

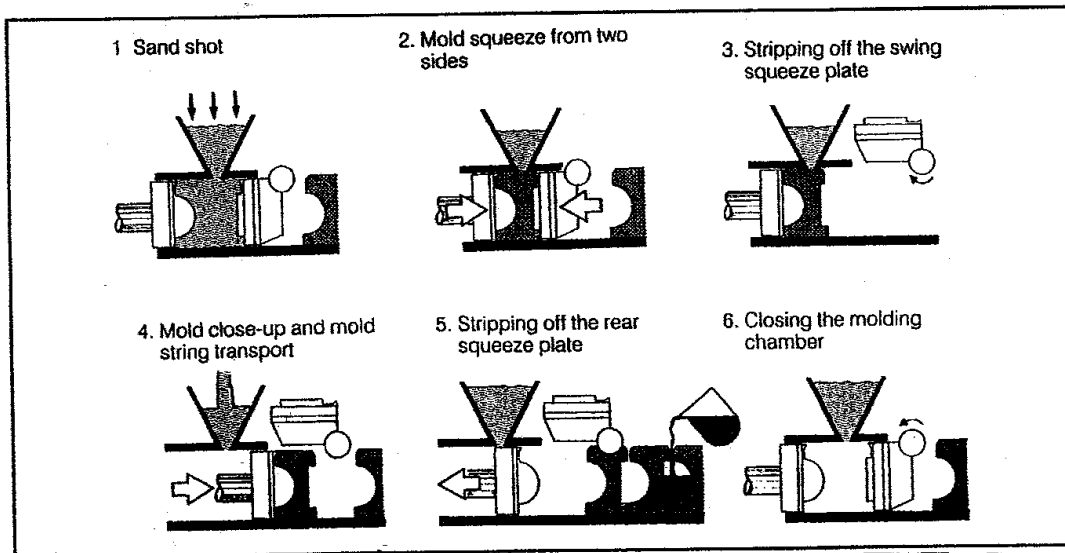


Exhibit AY

Machine layout

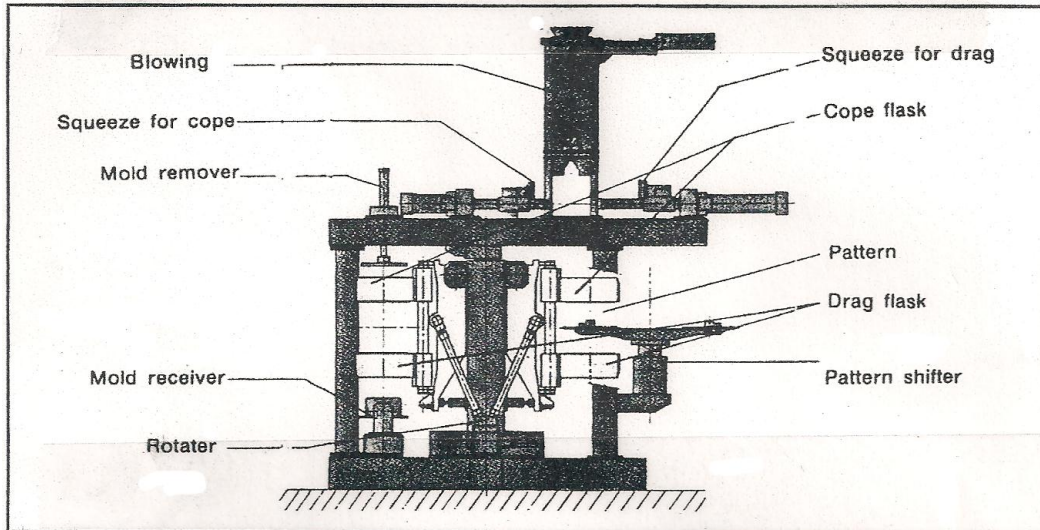


Exhibit AZ

Horizontally parted/vertically produced moulding sequence

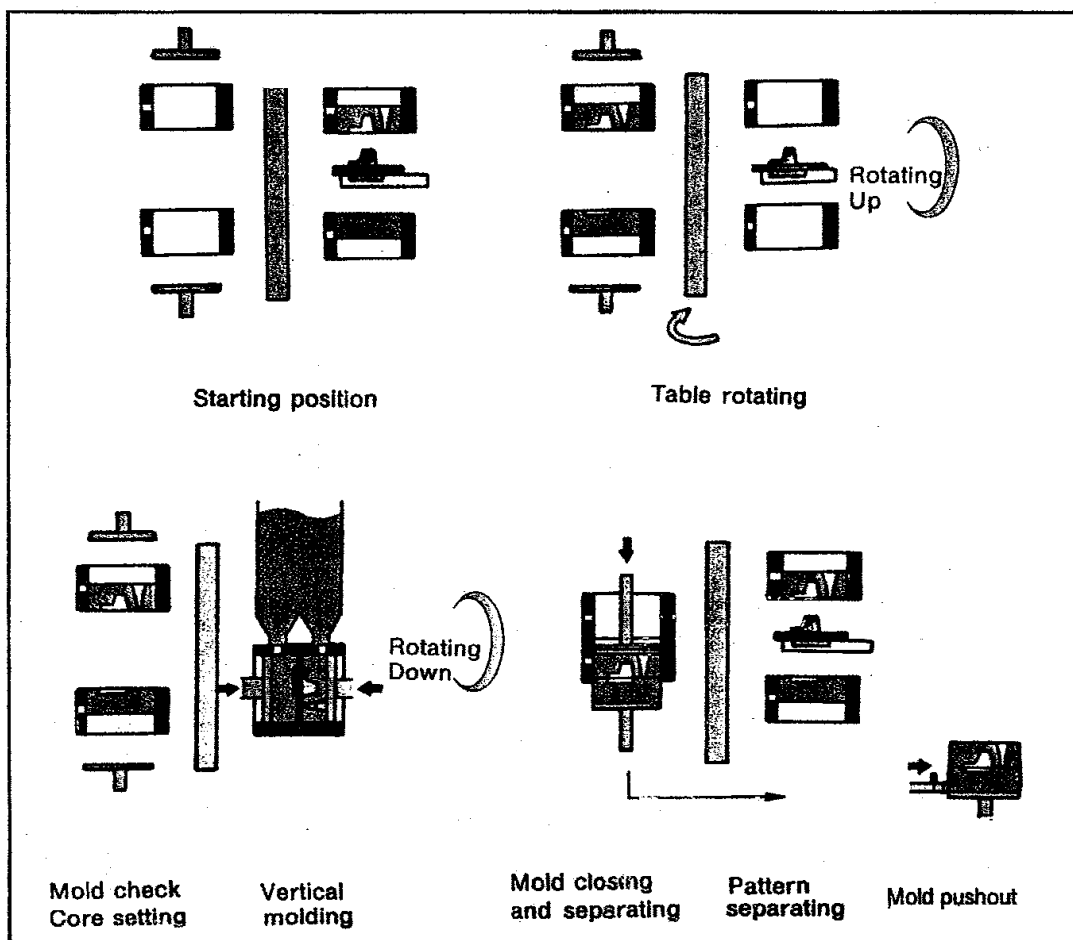


Exhibit BA

Mould blowing mechanism

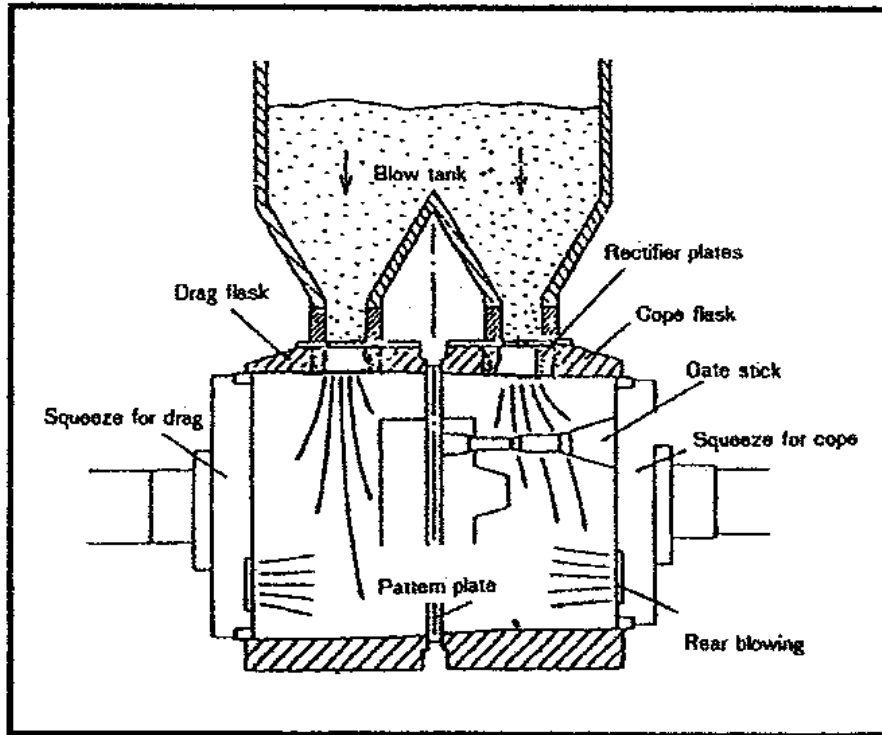


Exhibit BB Description of binder systems

Binder Group	Description
Alkaline-phenolic	An alkaline phenol formaldehyde resin, available in self-set or gassed variations.
Furane	A resin of urea formaldehyde and/or phenol formaldehyde and furfuryl alcohol, which is self-set with acids.
Phenolic-urethane	A phenol formaldehyde and isocyanate resin, available in self-set or gassed variations.
Silicate	An inorganic system, self-set using esters or gassed with carbon dioxide.

Exhibit BC**Typical addition rates for binders**

Binder Group	Typical Addition Rate
Alkaline-phenolic	1.5%
Furane	1.25%
Phenolic-urethane	1.0%
Sodium-silicate	3.5%

Exhibit BD

Operating sequence of typical shell moulding machine

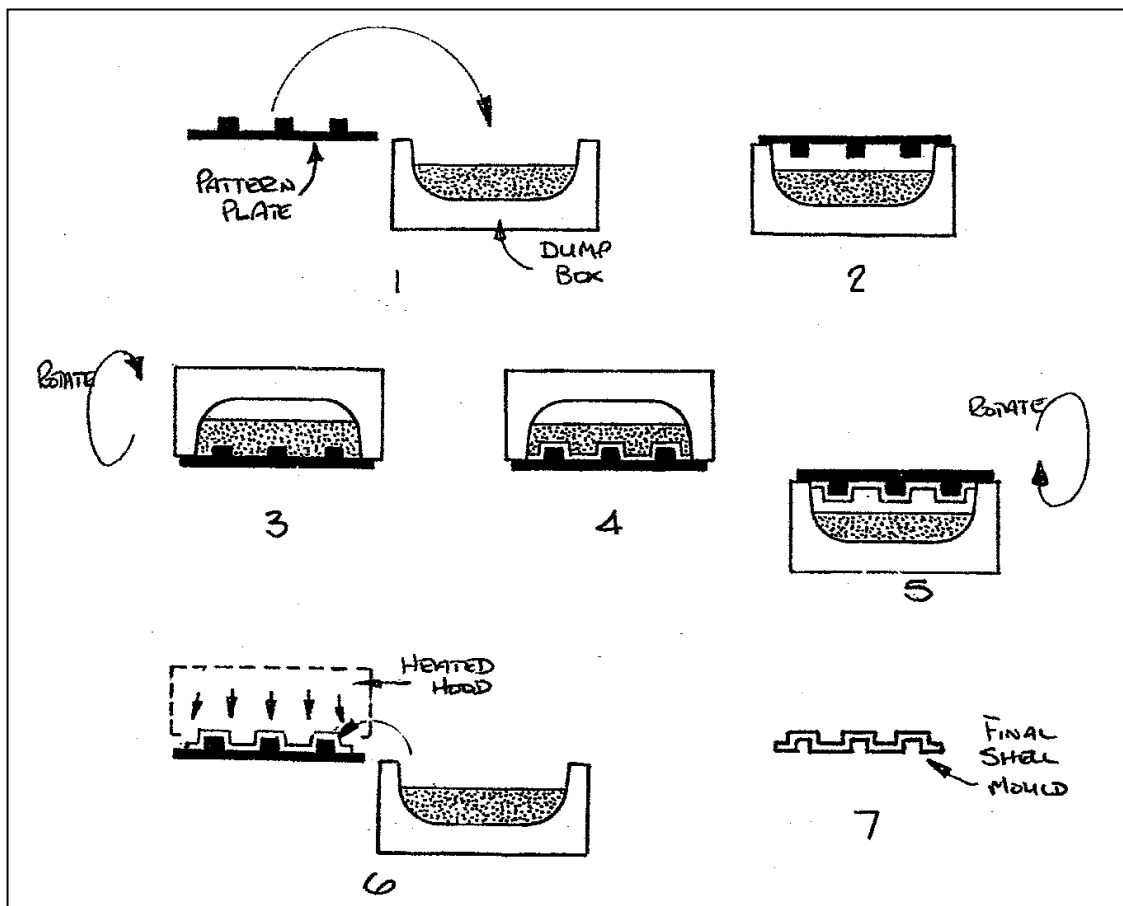


Exhibit BE Equipment for processing EPS

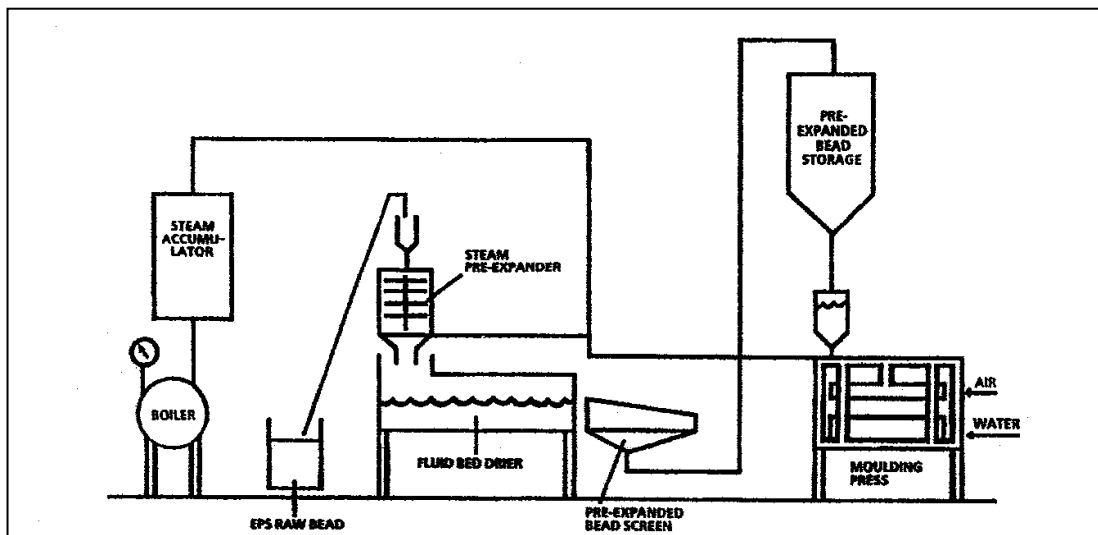


Exhibit BF

Moulding EPS

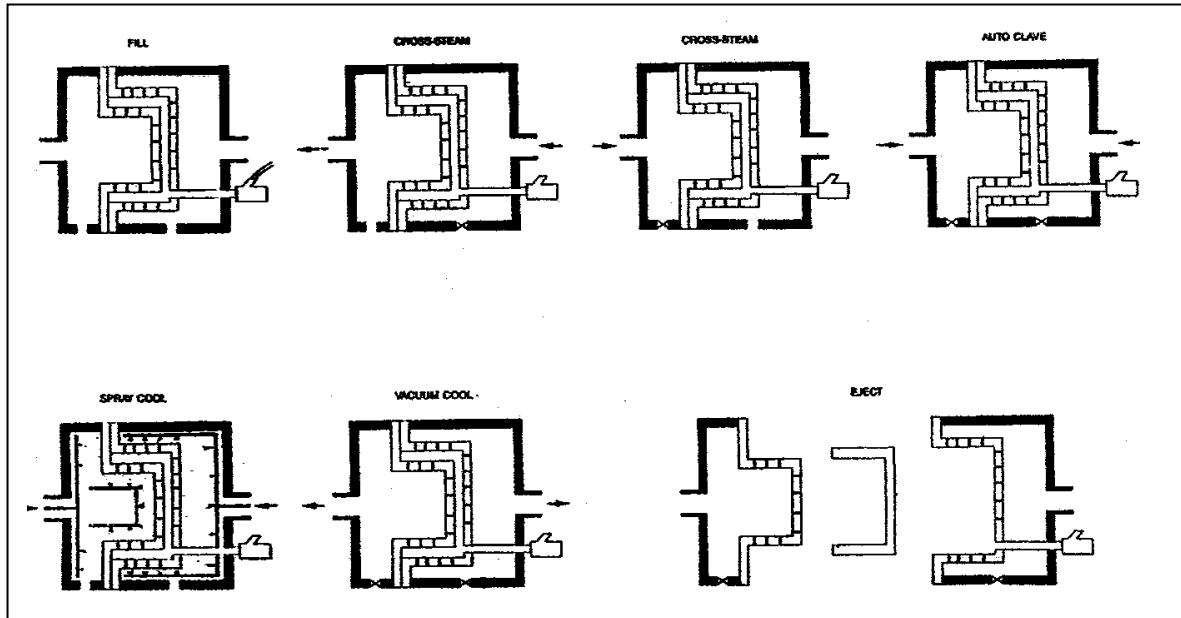


Exhibit BG

The lost foam casting process

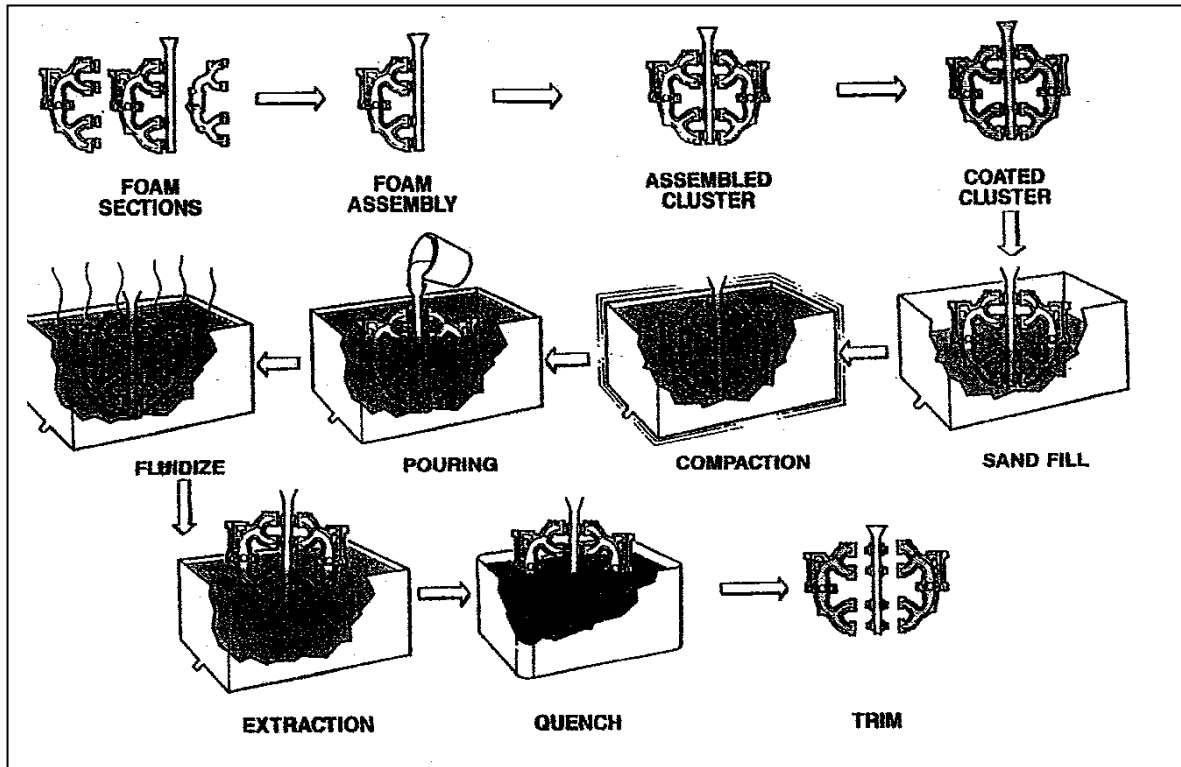


Exhibit BH Tolerances of foam patterns

Linear dimensional tolerances (including diameters and tolerances between hole centres) on regular shaped parts such as flat plates, straight bars, cylinders:

Dimension up to (mm)	Tolerance 3 x σ (standard deviation) mm
15	\pm 0.10
25	0.15
50	0.20
100	0.25
150	0.30
200	0.35
250	0.40

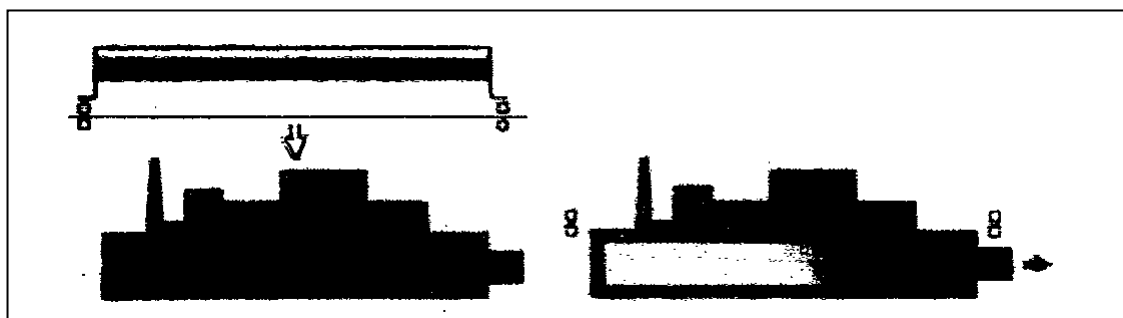
Tolerances are increased by about ± 0.20 mm when measured across a glued joint.

Tolerances of castings are at least 2 x pattern tolerance due to:

- distortion of the pattern during coating and sand filling
- variation in metal temperature and composition
- internal stresses arising during freezing and cooling of the casting.

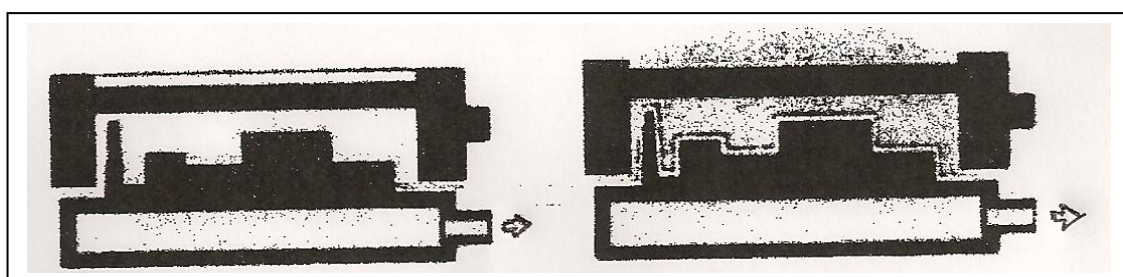
Exhibit B1

V-Process manufacturing stages



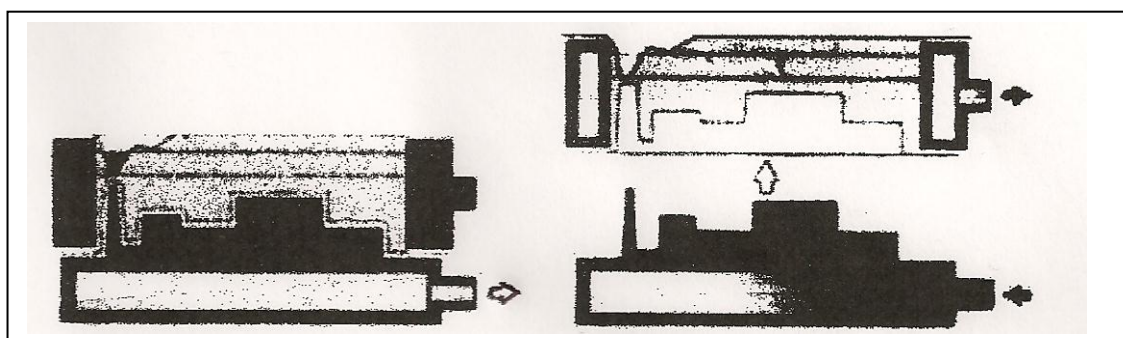
1 plastic film heater

2 pattern with plastic film



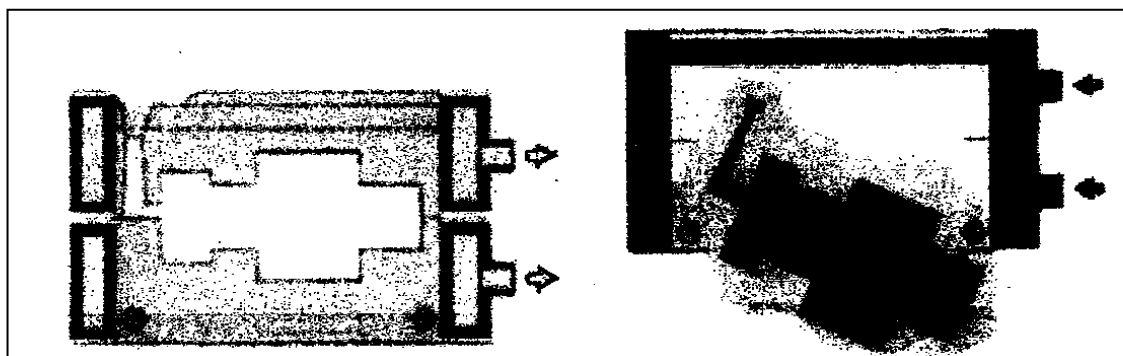
3 setting up the flask

4 sand filling and vibration



5 placing of covering film

6 mould stripping



7 castable mould

8 discharging

6.0 COREMAKING

6.1 Binder Systems

Equipment and resin/binder manufacturers are continually developing new processes, designing new equipment and refining and modifying existing designs. Exhibit BJ shows a list of core processes that is not exhaustive but covers many that are currently in use.

a) Hot Curing Processes

(I) Hot Box

The hot box process was developed and used in the early 1960s. By the late 1960s and into the 1970s it had become a significant process for the rapid production of cores particularly in the automobile industry.

Basic Principle

A heat sensitive liquid resin/catalyst system is mixed with sand to give a wet mix which is relatively stable at room temperature. The mix is then blown into a hot corebox where the latent acid catalyst is activated to cure the resin whilst in the corebox.

Resin Types

1	UF	This type of resin may contain up to 18% nitrogen. A typical application would be pillar tap cores cast in brass.
2	UF/FA	Nitrogen content at 9–12%. Reactivity is faster than straight UF with better strength. Cores can degrade when stored at high humidity.
3	PF	One system with virtually no nitrogen, but mixed sand is sticky and bench life short. Used for malleable cast iron.
4	PF/FA	Virtually a nitrogen free system. The furfuryl alcohol gives a brittle system and plasticisers may be needed to overcome casting defects. Flowability and bench life are good.
5	PF/UF	A development during furfuryl alcohol storage which now fulfils a niche market in its own right. Nitrogen contents can range from 1.5-11.0% depending on application.
6	PF/UF/FA	Generally low nitrogen levels – typically 3%. High strengths mean lower binder levels may be used.

Catalysts

All the resins used in hot box systems are heat/acid catalysed. Each particular system will have a specific catalyst depending on the properties of the mixed sand required. The acid catalyst may be in the form of an ammonium salt of a strong acid, a sulphonic acid or other buffered acids. Urea is normally a constituent of the catalyst. This reacts rapidly at corebox temperature with either formaldehyde or the resin, reducing fume evolution on cure.

Sand

Clean silica sand is the predominant base. Judicial blends of various sands may be made to minimise expansion.

Chromite sand has been used but its alkaline nature has adverse effects on the catalyst.

Sands for hot box system cores lie within an AFS Fineness No of 50–100 depending on casting finish required.

Sands with acid demands over 4 ml of 0.1 molar hydrochloric acid are not recommended.

Sand Temperature

The bench life of the sand is affected noticeably from winter to summer temperatures (i.e. 0°C – 25°C+). To overcome this difficulty, catalyst modifications are made to either reduce or increase the reactivity.

Mixer

Either batch or continuous mixing is appropriate, providing accurate resin and catalyst additions are made. The sequence of addition is not important compared to the efficiency of mixing which depends on well maintained mixing equipment to ensure both components are dispersed uniformly.

Resin Addition

The resin addition very much depends on:

- a) type of resin
- b) sand AFS grain fineness number
- c) handling strength required
- d) section of core

but levels falling between 1.25–3.0% are employed.

Catalyst additions on resin weight range from 10–25% but are designed specifically for each resin and must be weighed accurately.

Coreboxes

The hot box process is usually only used for making cores. Boxes are generally of cast iron or steel in order to maximise heat input into the sand.

Box temperatures may range from 180–240°C. A thick skin of cured sand is formed very rapidly and the remaining sand continues curing after ejection from the box to give a solid rigid core.

High box temperatures give surface friability with high nitrogen containing binder.

Both gas and electricity are used as energy sources.

Core Jointing

Adhesives are not commonly used but where essential a conventional glue can be used.

Refractory Coatings

Hot cores and cold core assemblies requiring refractory coatings are usually dipped into water based products. Drying is ensured by passage through tunnel ovens on a conveyer belt system. Different refractories are used for specific castings but many coatings are based on graphite and silica.

Casting Performance

This depends very much on the type of resin used and the metal cast. Figure 54 serves as a guide.

Sand Reclamation

Sand reclamation is not generally practised because hot box cores are used with greensand moulds. However, thermal reclamation would give satisfactory recycled sand.

(ii) Warm Box

This relatively recently introduced process is very similar to the hot box process. A wet sand mixture is prepared using a liquid furan resin and a liquid catalyst and the mixture is blown into a corebox heated to approximately 150–190°C.

Catalysts

The key factor in this lower temperature system is the catalyst which is based on the copper salt of paratoluene sulphonic acid or hydrochloric acid, either in an aqueous or a methanol solution. The catalyst is very stable at room temperature, but starts to dissociate or break down at 80–100°C and has maximum reactivity at 150–170°C.

As the catalyst is very stable at room temperature, bench life of sand mixtures can be up to 24 hours, although for high reactivity systems requiring good through-cure for large size cores the catalyst strength can be adjusted by altering the free acidity which will shorten bench life.

Copper salt catalysts must not be allowed to contact metal components in mixers or copper will be deposited. Plastic tubes and pump components must be used.

Sand Requirements

For efficient use of binders and for the attainment of the potentially very high tensile strengths which can be achieved by this process, it is necessary to use a high grade silica sand. For some applications where excellent casting surface finish and freedom from expansion-related defects such as finning is required, the process can be used successfully with non-siliceous sands such as zircon and chromite.

Best results are obtained, as for other resin-based binder systems, when pure, rounded to sub-angular grain silica sands are employed.

Sand Mixing

Any type of sand mixer is suitable, from batch type to continuous units. For some high speed applications with shorter bench life mixtures, foundries have installed small individual, low cost, low output continuous mixers on top of each coreblower, sand being used immediately after mixing. In many cases foundrymen use the batch to batch

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mixer and sand is delivered to each blower on demand, taking advantage of the long bench life.

Resin Additions

For silica sands, normal resin addition rates of 1–1.5% are used, based on sand weight. Catalyst addition levels are typically 10–30% based on binder weight.

For zircon sands, resin additions would be approximately 0.8–1.2% based on sand weight with catalyst levels at about 30% based on binder weight.

Coreboxes

As the pattern is heated, iron, steel or aluminium must be used.

Refractory Coatings

For many applications, casting surface finish is very good with this binder and coatings are often unnecessary. When extra refractory protection is needed, water based or spirit based ‘flame-off’ coatings are suitable.

Performance

Warm box offers high reactivity at lower box temperature and often at a lower nitrogen content than the hot box system.

(iii) Shell

This requires the use of a special resin-coated sand, which is normally purchased from a supplier though a few foundries produce their own in-house.

The process is similar to that described in Section 5.5 for shell moulding, in that the resin curing mechanism involves the transition from thermoplastic to thermosetting plastic in a limited time during the cycle, before the heat begins to decompose the binder.

Normally, however, shell cores are produced as a single hollow shell, the thickness of which depends on the cure time applied.

Shell cores have been used in foundries for a number of years and are produced on gas-fired machines which operate on a blow, invert, drain, cure and strip cycle. The main

use for shell cores is when small cores or a good surface finish are required. If insufficient cure time is given, shell cores cannot withstand molten metal pressure during pouring, though some foundries fill them with loose moulding sand, an extra operation, to overcome this. The limiting factor is that a minimum time must be applied to cure the core while it is in the corebox, which restricts output rates, though multi-impression coreboxes are used for very small cores.

Because the shell process operates above 250°C and requires a constant, uniform transfer of heat into the coated sand, grey iron is the usual shell corebox material. Grey iron coreboxes combine good heat capacity with acceptable thermal conductivity and recovery. Compacted graphite iron, however, is now recognised as an even better corebox material because of its superior resistance to damage from thermal cycling.

b) Cold Setting Processes

There are many cold setting or no-bake processes and the coremaking binders used are similar to those described in the chemically bonded moulding part of Section 5.4.

All no-bake processes are designed around a continuous mixer that mixes binder with the sand, adds catalyst and disperses the mixture into the corebox.

A no-bake binder system begins to cure the instant it comes into contact with the catalyst. How fast it cures depends on:

- type of resin
- sand chemistry
- percentage and type of catalyst
- temperature.

The sooner no-bake sand can be used after it has been mixed, the stronger and better core it will make.

Operating in the optimum 20–30°C temperature range reduces liquid catalyst use to the minimum and may also permit less resin to be used. Reducing resin content improves flowability and these changes may increase density enough for the sand to have the same tensile strength as sand with more resin.

Modern mixers incorporate programmable controllers which adjust the binder and catalyst contents to compensate for temperature variations.

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A major advantage of this room temperature system is that it can be used to produce low-volume and large cores using wooden coreboxes. This reduces the cost of tooling manufacture for smaller foundries.

To improve core properties it is necessary to densify the coated sand once it has been put into the corebox. This can be achieved by using a vibrating compaction table, by hand ramming, tucking or, with the largest cores, walking on the sand.

Capital costs of a new facility tend to be lower than for the other coremaking methods considered in that only a mixer is required – there is no core machine to purchase. However, the time taken to produce each core restricts the process' use to lower-volume components. Semi-automation can be achieved by having a number of coreboxes operating in a loop system around the mixer.

To meet environmental regulations, foundries must ensure that process management is strictly controlled and that proper preventative maintenance is carried out on tooling and machines.

c) Vapour Curing Processes

(I) Phenolic Urethane – Cold Box

This is the most widely used organic cold box process, having been introduced in 1968. It is principally used for high production automated core-blowing applications, although it can be used for small mould production.

Basic Principles

The process is based on classical polyurethane technology employing a three part system catalysed with gaseous amine.

Part 1	A specially synthesised, hydroxy functional phenolic Novolak resin, possessing high benzylic ether linkage and dissolved in organic solvents.
Part 2	A solution of methylene bis-phenylisocyanate (MDI) dissolved in organic solvents.
Part 3	A volatile tertiary amine catalyst selected from triethylamine (TEA), dimethylethylamine (DMEA) or, less commonly, diisopropylethylamine (DIPEA).

The reaction involved is catalysed poly-condensation between the phenol formaldehyde polyol component and polyisocyanate to form a polyurethane resin. There is no

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thermally related expansion or shrinkage in core production and good dimensional accuracy is normally obtained.

The amines are converted into vapour before passing through the binder sand mix. DMEA is more reactive than TEA, with a higher vapour pressure and more pungent smell. DIPEA is claimed to be only a little less reactive than DMEA, with much reduced odour.

Sand

Ideally clean silica sand of 250–280 microns average grain size (AFS 50–60) should be used, but the process works well with 150–375 microns average grain size (AFS 40–90). Acid demand should be low since alkalinity promotes reaction of Part 1 and Part 2, reducing bench life and general performance. Clays and oxides produce a similar effect.

Low moisture is of paramount importance. Ideally, this should be 0.1% maximum. Water reacts with Part 2 in the manner shown in Exhibit BL.

Other reactions involving the amine and isocyanate groups also lead to a consumption of Part 2 resulting in reduced cross-linking density. Overall, this reaction causes reduction in bench life, flowability, strength, etc. Air used in the process as a carrier or purge should be as dry as possible. Heating the purge air improves immediate strength.

Mix Composition

For ferrous metal castings, total binder levels of typically 1.5% are used, though the system can be operated as low as 0.8%. Part 1 and Part 2 are normally formulated to give the best overall results when used in equal proportions. Varying binder ratios can favour one property or another. For example, ratios favouring Part 1 improve as-gassed strength and reduce gas-related problems, whilst favouring Part 2 increases thermal stability and core storage.

Amine requirements are dependent on core size and complexity but an average figure is 2–5% of total binder level. Correct venting and good corebox sealing are of paramount importance in economic and efficient use of amine.

Mixers

Zero retention continuous mixers are ideal, particularly if arranged to give direct feed to the blower hopper. Low speed, single screw units can also be used successfully.

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Batch mixers are well suited to the process, particularly if binder levels are to be varied or when making dry additions such as iron oxide.

Coreboxes

Grey iron is the most commonly used construction material, although aluminium alloy metals, epoxy and urethane resins have been used successfully.

Coatings

Several types of core wash can be used including water, alcohol and chlorinated solvent based, applied by dip, spray or over-pour technique.

Cores should be aged for some time before application of coatings to prevent softening of the core surface.

Casting Performance

Surface Finish – this is generally excellent due to formation of lustrous carbon. However, excessive lustrous carbon formation can result in lustrous carbon defects. Iron oxide addition or change in ratio in favour of Part 1 may resolve the problem.

Veining – some veining/finning may occur in the certain casting configurations. This may be reduced by lowering binder level, iron oxide additions, starch or cereal additions or an insulating refractory coating.

Breakdown – generally excellent after casting in ferrous metals. Shake-out in aluminium castings may be improved by increasing Part 1.

Gas Evolution – some problems have been reported resulting, it is believed, from nitrogen. Iron oxide reduces this problem.

Hydrogen pinholing can occasionally occur in aluminium and some iron castings.

Sand Reclamation

The excellent breakdown properties make reclamation a relatively easy operation. However, since fines contain a high proportion of binder residues, careful re-classification and control of fines is essential if casting defects are to be avoided. Only

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sands from the urethane cold box and cold set processes, which are chemically compatible, are suitable for reclamation and re-use.

Only a limited amount of reclaimed urethane core material (25% max) should be allowed into a greensand system to avoid deterioration in properties.

Loss on ignition must be below 2%. The excellent burn-out characteristics generally allow such levels to be achieved easily with ferrous castings.

(ii) Sodium Silicate/Carbon Dioxide

First introduced in the 1950s, the process has grown to find very wide application in mould and core production, light and heavy casting in a range of metals.

Basic Principle

Hardening of the silicate is effected by passing CO₂ through the sand binder mixture.

Binder

Breakdown after casting can be a problem due to the sintering effect and the non-organic nature of the bond. This condition can be eased by additions of organic materials such as wood flour, sugars, starch or coaldust. However, a fall in bench life and core shelf life and strength will result. Formulated silicates are available for use as one-shot binders, which give improved core properties and breakdown.

Silicates having ratios of SiO₂:Na₂O from 2.0:1 to 3.3:1 are normally used. The higher ratio silicates give faster gassing, less CO₂ usage and better breakdown, but suffer from a fall-off in core properties when over-gassed.

Lower ratio silicates are more resistant to over-gassing. Modern one-shot silicates using carefully selected glucose or acrylate polymers largely overcome the above compromise situation and in some cases prove very effective binders in ester set work.

Sand

Most commercial sands can be used and since the presence of many impurities such as alkalis, does not greatly affect cure, sea sands may also be used. Clay markedly reduces strength and storage properties and should be kept as low as possible. As with ester set systems, sand temperature should be controlled and within the range 15-35°C.

Mix Composition

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This will vary dependent on core strengths required and sand granulometry, but 2.5%-3.5% is a typical range.

CO₂ consumption is dependent on many factors and although the theoretical quantity is 0.2% per 1% of binder present, in practice much higher levels are needed, up to near 1% per 1% of binder.

CO₂ Dispensing

CO₂ is available in three forms:

- a) **Gas Cylinders** – CO₂ as a gas under high pressure is dispensed through a reducing valve to a line pressure of 15–20 psi. Such pressure reduction causes a significant fall in temperature and it is usual to incorporate some form of heater in the line to meet production demand.
- b) **Bulk Liquid** – as a liquid cooled to -20°C and pressurised to 18.6 bar (270 psi). Delivered by road tanker and stored in refrigerated tanks. This method of delivery offers significant cost advantage in CO₂ purchase. A simple high pressure vaporiser is then required.
- c) **Syphon Cylinders** – these are conventional cylinders containing liquefied gas where the liquid is drawn off by a syphon tube below the surface. As with the bulk supply, a suitable high pressure vaporiser is required.

On the question of economic use of CO₂, it must be stressed that this is greatly influenced by sand and gas temperature, gas pressure and volume, as well as number and positioning of vents in the corebox.

Consumption is also dependent on quantity and grade of silicate.

Modern one-shot binders have contributed much to improvements in speed of gassing for given core strength.

Mixers

Continuous, on-demand screw-type mixers are well suited to the process, especially with one-shot binders. Hopper and metered feed arrangements are required if powder breakdown agent is to be used. Liquid agents present less of a problem, but in both cases addition should be made as early as possible.

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Batch mixing is quite satisfactory for the process, with a mixing rather than a milling action being preferred. Mixed sand should be transferred without delay to a covered bin or other reasonably airtight container

Core Production

Both core blowers and shooters are widely used with the process.

Methods of introducing the CO₂ gas into the boxes are:

- probe gassing
- sealed hood gassing
- through pattern gassing
- vacuum cabinet.

Coreboxes

Most traditional materials can be used. Wooden boxes should be coated with paint resistant to silicate, eg polyurethane or epoxy. With smooth, flat surfaces, stripping is usually excellent even without parting agent. The latter should be used sparingly. Aluminium boxes should be coated to avoid attack from the sodium silicate.

Refractory Coatings

Alcohol and chlorinated solvent-based coatings may be used and applied by swab, brush, spray or overpour. Importantly, with this process powder coating can be applied successfully by the electrostatic technique. Water-based coatings are not recommended because of adverse effects on bond strength.

Casting Performance

Surface Finish – excellent strip and glass-like surface usually provides a good casting finish.

Penetration – problems are minimal.

Burn-on – with heavy section castings and high pouring temperatures it is advisable to coat with refractory dressing.

Metal/Mould Reaction – there is little chance of such reaction since the system is free from nitrogen, sulphur and phosphorus. Gas evolution is low.

Erosion – generally good resistance to this defect.

Breakdown – poor. Not as good as organic binders but suitable for many purposes if based on formulated silicate containing breakdown agent.

Hot Tearing – CO₂ silicate is susceptible to this defect.

Veining – no problems.

Sand Reclamation

This process does not reclaim economically by dry attrition but wet reclamation allows higher levels to be used, however, at significant cost penalty.

(iii) Carbon Dioxide Cured Alkaline Phenolic Resin

Introduction

The process is a core and mould making system comprised of an aqueous alkaline phenol-formaldehyde resole resin and carbon dioxide.

Sand Requirements

The process is suitable for most sand types but is not recommended for olivine sand. Silica sands should be washed and dried, of round to sub-angular grain shape and ideally 225–275 microns average grain size (50–70 AFS).

Both zircon and chromite sands may be used.

Sand temperature should be in the range 16–32°C.

Sand Mixing

Both batch and continuous mixers may be used. With batch mixers of the 'S' muller blade type, mixing time should be 2–4 minutes. High intensity bowl mixers require a minimum of 40 seconds to ensure adequate mixing but no longer than 120 seconds.

Any good conventional continuous mixer will provide adequate mixing.

Mixed sand bench life is typically up to 4 hours with cool sand and will be reduced to around 1 hour for sand at 30°C.

Resin Addition Rate

Binder addition level is dependent upon the sand type and core dimensions. For silica sands, 2.0% to 3.0% based on sand weight is recommended.

Zircon and chromite sands will require a lower binder percentage, 1.8% to 2.5% based on sand weight.

Carbon Dioxide Gassing

The **static pressure gassing** method should be used for best results. Typically, this will require 0.5% to 1.0% carbon dioxide gas based on sand weight.

The static pressure technique involves filling the box with CO₂, sealing and allowing the reaction to take place under pressure.

The second most effective technique is the **restricted gassing** method. Typically, this will require 1.0% to 2.0% carbon dioxide gas based on sand weight. The restricted

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gassing technique involves limiting the core vent area to restrict gas flow and allow reaction under partial pressure.

Gas temperature should be 21–35°C, supplied from a high pressure vaporiser. Unrestricted gassing through an open box with excessive vent area is not recommended since it can result in incomplete curing.

Use of unvented boxes is not recommended.

Corebox Material

The process is compatible with wood, metal (ferrous only) and plastic (urethane or epoxy) corebox material.

Vent types recommended are screen (woven) or slats.

Refractory Coatings

For many applications, casting surface finish is satisfactory with this binder and sometimes coatings are unnecessary. When extra refractory protection is needed both water and solvent-based coatings can be used. Application can be accomplished by all conventional methods; dipping, spraying, swabbing and brushing.

Environmental Benefits

The process offers a non-flammable system with no odour during mixing and coremaking and very little fume on casting.

Unlike some cold box systems, the process does not require scrubbers.

Casting Performance

The process contains no phosphorus, nitrogen or sulphur and consequently defects associated with the presence of these elements are eliminated.

Finning or Veining – does not occur and lustrous carbon defects are virtually eliminated.

Breakdown – satisfactory.

Surface Finish – usually good.

Gas Evolution –low.

(iv) Carbon Dioxide Cured Acrylate Resin

Introduction

Polyacrylate-based resin binders have only relatively recently become available for foundry mould and core-making. They are available at present as carbon dioxide gas

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hardened binders offering good environmental properties. Current applications are largely restricted to core-making.

Basic Principles

The carbon dioxide gas temporarily changes the pH of the compacted mixed sand in the mould or corebox and this serves to precipitate the polyacrylate resin as an insoluble polymer which is believed to be ionically 'cross-linked' by calcium ions provided by a powdered hardener component in the sand mixture.

The rate of curing reaction is rapid and is relatively unaffected by temperature in the range 5°C to 30°C.

Sand

As the sand mixture containing the polyacrylate binder is alkaline, the system is compatible with a wide range of sands including alkaline types such as zircon, chromite, olivine and some seasands. Acidic sands should be avoided.

Sands should have less than 0.3% clay for best results and should have an average grain size of 200–300 microns.

Mix Composition

Resin – typically 2.5% – 3.0% of the sodium polyacrylate resin based on sand weight.

Hardener – 1.4% based on sand weight.

These materials can be handled easily as the resin is a non-toxic, neutral aqueous solution of sodium polyacrylate. The hardener is based on slaked lime and, apart from avoiding the creation of a nuisance dust hazard, there are no special handling requirements for either component. There are no restrictions on materials for pumps, lines, valves, etc.

Mixer

Polyacrylate binders can be mixed in batch or continuous mixers but if continuous mixers are to be used, a powder feeder is required for the hardener component.

Coreboxes

Polyacrylates are suitable for use with wood, metal or epoxy resin patterns and coreboxes. As the binder system is alkaline, special alkyd paints, as used for CO₂ silicates, should be employed to protect wooden boxes, and aluminium boxes need some polyurethane-based protective paint, or regular cleaning, to prevent alkali attack.

After use, boxes should be washed with warm water to remove any adherent binder.

Coatings

The use of refractory coatings is advised for iron and steel castings to ensure a good casting surface finish without burn-on. Light alloy castings have been made successfully without coatings to a high standard of finish.

Spirit-based (flame-off) coatings or air-dried coatings should be used, water-based coatings are not recommended. Coatings should be applied preferably by spraying, swabbing or painting.

Vapour Generators

Carbon dioxide is normally obtained from bulk supplies of pressurised, liquified gas, although for small operations cylinders (syphon or non-syphon types) can be used. When bulk storage or syphon-type cylinders are used, the liquified CO₂ must be vaporised before use. Vaporiser units and pressure reduction equipment are readily available from CO₂ suppliers

It is recommended for economy in gas consumption that flow control/timer units are used for dispensing the gas to ensure optimum gassed strengths with minimum CO₂ usage.

Typical gas consumption for curing cores to optimum strength is about 1% of the mould or core weight.

A recent development has seen the use of methyl formate vapour entrained in the CO₂ gas supply to enhance the curing operation. Higher immediate strengths are possible and gassing times are reduced.

Casting Performance

Surface Finish –

Aluminium	satisfactory cores uncoated.
Iron/steel	satisfactory if coatings are applied, severe burn-on possible if no coating is used

Metal Penetration – no known problem if adequately compacted cores are used.

Mould-Metal Reactions – there is no nitrogen, sulphur or phosphorus present in the binder and therefore there are no related pinhole or surface structure defects in castings caused by absorption of these elements into the molten metal.

Erosion – the low thermal degradation of polyacrylates can lead to premature weakening of the surface of moulds or cores during casting. This can be a problem for

heavy castings, especially around ingates, and a highly refractory coating applied to sensitive areas can be beneficial.

Breakdown – polyacrylate binders give excellent core breakdown in iron, steel and most non-ferrous castings.

Hot Tearing – there is a slight tendency for hot tearing in some susceptible malleable iron castings.

Finning – no known occurrence of finning defects.

Sand Reclamation – limited experience suggests dry attrition reclamation may be possible, although it is only possible at present to re-use reclaimed sand at 50% to 60% levels.

Environmental Benefits –

- Non-toxic aqueous-based resin.
- No phenol formaldehyde or MDI content so very little risk of environmental hazard in the foundry. Binder breakdown on casting is not known to give any hazardous concentration of dangerous organic chemicals.
- Sulphur, phosphorus and nitrogen-free, so no risk of noxious organic chemicals.
- With current waste disposal regulations, waste sand is believed to be safe for disposal on licensed domestic tips.

(v) Sulphur Dioxide Cured Epoxy Resins

Introduction

The epoxy/SO₂ process was first introduced to the foundry industry in 1982 in the United States. The process has gained wide acceptance in the USA, largely as a replacement for furan/SO₂, but has had less success in Europe due to high cost and concerns over handling sulphur dioxide.

Basic Principles

Modified epoxy resins are mixed with an organic hydroperoxide on sand and cured by passing sulphur dioxide gas through the compacted sand mass.

Sand

The epoxy/SO₂ process is tolerant to most sands commonly used, but sands with very high acid demand should be avoided as this may affect bench life and strengths. Moisture contents should not be high and preferably below 0.2%.

Mixing

Both batch and continuous mixers are suitable. Viscosities of most formulations are low and dispersion is readily achieved. Some resin formulations are shear sensitive and should not be used with gear pumps. Suppliers should be consulted about suitable pumps

Resin Additions

Typical total additions are between 1.0% and 1.5% on silica sand. Epoxy resins work particularly well with zircon sands where additions as low as 0.45% total have been reported.

Modified Resins

There are many different formulations of modified epoxy resins, some of which have the peroxide included in one resin part, whilst others do not.

Epoxy resin systems for foundry use are modified by additions of phenolic resins or, more usually, acrylic resins. The acrylic resins used are similar to those used in the free radical process and such resins are sometimes referred to as hybrid free radical process/epoxy resins (see Section 3.4.1.3.9 – free radical process).

Acrylic modified epoxies produce better curing properties with fast gassing times, better cold and hot stability and higher initial strengths.

Coreboxes

Aluminium, iron, steel, wood or plastic coreboxes are suitable. Wooden coreboxes must be adequately sealed to avoid absorption of SO₂ and premature hardening of sand. Cellulose varnishes should not be used and two part epoxy or polyurethanes are preferred.

Venting requirements differ from the amine cured phenolic urethanes in that fewer vents are required to blow a well compacted core and venting can be better optimised for gassing efficiency. As a result, on complicated cores gassing times can be one third to one half of those required for phenolic urethane cores.

Generators

The basic requirement is to deliver a large volume of SO₂ at relatively low pressure (around 30 psi). Cylinders of liquid sulphur dioxide are usually heated to produce a gas

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pressure which fills a heated reservoir. This reservoir should be at least six times the capacity of the largest core volume to avoid pressure drop during gassing.

Gassing is followed by an air purge (preferably heated) to remove residual sulphur dioxide. Ideally, separate gas and purge lines should be used to avoid 'gassing' the cores with air prior to the SO₂ input. If a long common line is used, this raises gas times and in some cases can reduce strengths. Gas consumption is between 10% and 30% of total binder weight.

The use of exhaust gas treatment is essential. Suitable scrubber units are available.

Core Properties

Cores leave the box with up to 90% of final strength, depending upon the resin formulation and gassing efficiency. Strengths at this stage are typically 10–20% higher than for amine cured phenolic-urethanes.

Release of cores from the corebox is excellent due to very low resin build-up characteristics and core breakage is very low. The need for release agents and box cleaning is much reduced.

Bench Life

The mixed sand bench life exceeds 24 hours with most base sands and emptying and cleaning of core machines and mixers is not required on a daily basis. Cleaning of such items is usually a 'once a week' operation.

Coatings

All core wash types can be applied by all the usual techniques.

Aluminium castings require no coating for an excellent surface finish. Ferrous castings generally require a coating to avoid erosion, but there are some good erosion resistant formulations where coatings may not be required.

Casting Performance

Surface Finish – this is generally excellent, particularly with non-ferrous castings.

Veining – some veining tendency. More acrylic component in the formulation largely eliminates veining, but increases erosion tendency.

Shake-out – excellent with acrylic modified systems.

Gas Evolution – very low gas evolution and typically free from gas related defects.

Thermal Stability – generally excellent stability, except when modified with acrylics.

Sand Reclamation

Only used as a core process and reclamation is not normally practised as a unit sand system. Epoxy/acrylics are being reclaimed to a limited degree by attrition/thermal units in mixed process systems.

(vi) Sulphur Dioxide Cured Furan Process

Basic Principle

Sand is coated with a furane resin and a peroxide.

Sulphur dioxide is passed through the sand mix where it is oxidised to sulphur trioxide which dissolves in water from the binder to form sulphuric acid that rapidly polymerises the binder.

Sand

All clean dry sands of 125–375 microns average grain size (AFS 40–90) and having a low acid demand are suitable for this process.

Coolers/Heaters

The SO₂ furane process is very sensitive to sand temperature. Best results are obtained at sand temperatures of 25–30°C. A heater is required in cold conditions.

Mixers

Normal foundry batch or continuous mixers are suitable for the process. A bench life of up to 16 hours shows no fall-off in performance.

Sulphur Dioxide Generators

Whilst SO₂ can be generated and used from cylinders or bulk containers, the output is variable as the liquid temperature drops due to loss of latent heat. The two ways to deal with this are the same as those used in equipment for generating amines or methyl formate, i.e.:

- ‘on demand’ where the SO₂ is measured as a liquid onto a heater

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- ‘accumulator type’ where heaters are used to keep the SO₂ liquid/vapour at constant temperature during sequential gassing.

Typical proportions of binder, peroxide and SO₂:

- From 1.0% to 1.5% of furane polymer is used on the sand.
- 25% in weight of MEKP is required on the resin.
- 10% by weight of SO₂ is required on the resin. This is equivalent to 0.5 litre of SO₂ per 1 kg of core sand mix.

Corebox Materials and Sealing

Wood, epoxide, aluminium or steel boxes may be used, suitably vented to allow the blowing of fully packed high density core sand with complete penetration of SO₂ to all parts of the sand. The box must be sealed, usually by an ‘O’ ring in a slot in one half of the box. Sand should not be allowed to build up and prevent sealing.

The box must be surrounded by a ventilated cabinet to convey away any SO₂ fumes escaping from the box.

There is a tendency for a black coating of polymerised binder to build up on the box face. This can be minimised by the use of the correct furane polymer having a low free furfuryl alcohol (FA) content. The black coating can be removed by proprietary cleaner, eg Methyl 2-Pyrrolidone.

Purging/Scrubbing

Most of the SO₂ passing into the core reacts with peroxide but any excess must be purged with air. As SO₂ is such an irritant pungent gas with Occupational Exposure Standard Long Term exposure limits (8 hr TWA) or 2 ppm, it must be scrubbed from the air before discharge to atmosphere. This is best done using a 10% caustic soda solution in a specially designed flooded plate or Raschig ring scrubber. The sodium sulphite effluent must be treated with hydrogen peroxide to form sodium sulphate before disposal.

Refractory Coatings

Isopropanol, aqueous or evaporative refractory coatings can be used with SO₂ furane. Care should be taken not to overheat aqueous based coatings when drying as this reduces core strength. 115–120°C appears to be the ideal temperature.

Casting Performance

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SO₂ furane cores and moulds produce castings in iron, steel and aluminium of good surface finish with no penetration or burn-on. Nitrogen pinholing is not a problem and no lustrous carbon defect has been observed. Erosion is negligible and breakdown good. Some hot tearing has been observed but little finning.

(vii) Ester Vapour Cured Alkaline Phenolic Process

Introduction

The methyl formate cured alkaline phenolic resole system was first introduced in 1983. The process has gained substantial acceptance world-wide in applications where improved environmental conditions are required in mass production foundries.

Basic Principles

The alkali in the phenolic resole resin reacts with the volatile ester (usually methyl formate) to form the alkali metal salt of the acid component of the ester releasing the alcohol component.

Sand

Because of its alkaline nature, the phenolic ester system is suitable for most types of sands, including the alkali types, eg seasand, clay bearing sands, olivine, chromite and zircon. Thus alkali demand becomes more important than acid demand and very acidic sands require special treatment.

The normal relationship applies between grain size, shape and distribution, surface cleanliness and strength.

For most core and mould purposes sands having 125–325 microns average grain size (AFS number 45–80) are used. Use of coarse sands requires a refractory coating to enhance surface finish.

Sand Temperature

Sand temperature can influence performance. Optimum sand temperature is 10–30°C.

Mixing

The sand binder mix can be prepared using either batch or continuous mixers. It is important to check that only alkali resistant components are used for the pumps, lines and mixers for this system.

Bench Life

Sand binder mix must be covered to avoid crusting when stored in warm weather. Freshly prepared mix gives the highest strength, although it can be used up to 8 hours.

Resin Additions

250–300 microns average grain size (AFS 50–60) silica sands require from 1.2–1.8% addition of resin to obtain moulds and cores of suitable strength. Zircon sand requires 1.0–1.25% addition of resin.

Coreboxes

Wood, plastic (polyurethane or epoxy) and steel patterns can be used. Aluminium patterns should be coated with polyurethane to prevent attack by alkali. Cellulose or shellac varnishes should not be used.

Correct venting of moulds and coreboxes is essential for this process so as to ensure contact of every part of the core with methyl formate vapour. Blown cores require a correct balance of vents for vapour transmission. Special blowing vents that close during gassing are available. Self cleaning or mesh vents should be used. The correct size and placing of vents must be determined by experiment for each corebox to obtain best results from the process with the minimum use of methyl formate.

Methyl formate usage as a percentage of resin depends upon its alkali content, but usually varies from 10–30%.

Adhesives

It is possible to use all normal air drying and heat setting core adhesives without problems. The manufacturer's instructions should be followed.

Refractory Coatings

Water-based – the surface of the core or mould that represents the casting surface should be pre-warmed by torching, taking care not to blacken the surface. Apply the wash by painting, spraying or dipping. Re-dry by torching or in an oven. Avoid wet spots.

Alcohol-based Fired Coatings – care should be taken not to apply the coating until the surface of the mould or core is hard. If in doubt, torch dry. The alcohol should be ignited immediately after coating. Do not allow to air dry. Ensure that all the alcohol has burnt off from deep draws of the mould.

Chlorinated Solvent-based Air Drying – follow the manufacturer’s instructions. These coatings are not recommended for environmental reasons.

Casting Performance

Good performance with no signs of lustrous carbon defect, nitrogen pinholing and other defects. Low gas evolution. There is a tendency for veining on some steel castings.

Reclaimed Sand

The methyl formate cured alkaline phenolic resole system can be reclaimed up to 80% with conventional dry attrition units. Cores are compatible with greensand.

(viii) Methylal Cured Acid Phenolic Resin Process

Basic Principle

Highly reactive, phenolic type compounds and their oligomers are used as binders in this process. They are cured under acidic conditions by the additions of formaldehyde donors. Low boiling acetals such as methylal function as the formaldehyde donors. Organic solvents are not required. Neither free phenolic nor free formaldehyde are present in the binder.

- | | |
|--------|--|
| Part 1 | The resin is an aqueous solution of highly reactive phenolic compounds. |
| Part 2 | The acid is a concentrated aqueous solution of various types of sulphonic acids and mineral acids. |

Sand

The process is suitable for use with silica, zircon and chromite sands but olivine sand does not cure due to its high alkalinity. Washed, clean silica sand of 250–280 microns average grain size (AFS 50–60) is generally used, but silica sands of up to 90 AFS have also been successfully used.

Mix Composition

The addition levels depend on the desired core properties. They vary between 0.8 and 1.4 parts by weight of the resin and 0.5–0.9 parts by weight of the catalyst on the sand.

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The desired strength level of the core components and the development of strength during the curing process in the corebox and after stripping, depend on several parameters. In addition to the choice of the type and amount of reactants, the following factors are pre-requisites for good core production:

- the corebox must be vented so that the acetal contacts all parts of the sand core
- the corebox temperature should lie between 35°C and 40°C
- the reaction is favoured by warm sands, reclaimed sands need not be cooled below 40°C.

Mixers

Both continuous and batch mixers can be used.

Coreboxes

Metal coreboxes are generally used.

Vapour Generators

Generators are available from manufacturers for the accurate dispensing and control of methylal.

Refractory Coatings

Cores can be coated immediately after stripping from the corebox or equally as well days later. Alcohol and water-based coatings are suitable.

Casting Performance

Surface Finish – excellent with non-ferrous casting and no problems experienced to date with the limited trials conducted in the production of ferrous castings.

Breakdown – excellent.

Sand Reclamation

Limited experience has been gained on the reclamation of sand used in this process but has shown encouraging results.

(ix) The Free Radical Process*Introduction*

Developed in the USA in 1982, the process has achieved limited acceptance both there and in some European countries.

Basic Principles

The binder is composed of unsaturated urethane oligomers and acrylic monomers. An organic peroxide initiates the free radical polymerisation via sulphur dioxide during gas curing.

Base Sand

The process is tolerant to a wide range of sand types and being a neutral curing mechanism is not greatly affected by the pH of the sand, but for maximum bench life a neutral value is preferred. Moisture content must be less than 0.2% to avoid large strength reductions.

Some grades of zircon sand have been found to give poor results due to rapid core deterioration. The reasons for this have not been identified. However, the process works well with chromite sands.

Mixing

The process is generally offered in two component forms – binder and organic hydroperoxide, suitable for both batch and continuous mixers. The peroxide is only added at 3% of the binder weight and should be pre-mixed with the binder. This pre-mix is stable for several days and can be pumped conventionally. Alternatively, an accurate metering pump can be used to deliver the peroxide into the resin pipe close to the mixer input point.

Resin Addition

Typical additions would be between 1.0% and 1.5% on silica sand for aluminium applications. For ferrous applications 1.3–2.0% is used.

Coreboxes

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Aluminium, iron, steel, wood or plastic coreboxes are all suitable. Wooden coreboxes must be adequately sealed to avoid absorption of SO₂ and premature hardening of sand.

Brass vents are best avoided due to a reaction with the peroxide which results in an uncured spot around the vent. Care should be taken to ensure that coreboxes are cleaned regularly.

Generators

The process only requires very small quantities of SO₂ for curing. Around 5–10% SO₂ is blended with either carbon dioxide or nitrogen through flow regulators and passed into a heated holding tank. The pressure of this mixture should be maintained around 30 psi and gassing is carried out at 5–15 psi. Purging is carried out with dry air (preferably heated) to remove residual SO₂. Improved performance can be achieved by pre-purging cores with nitrogen prior to gassing with the diluted SO₂. This removes oxygen (air), which may interfere with curing, from the gassing lines and the core.

SO₂ consumption is very low at only 1–2% by weight of the total binder weight. The use of exhaust gas treatment is necessary in some cases. Suitable scrubber units are available.

Core Properties

The process exhibits very rapid curing properties so gassing times are extremely low. Strengths are similar to phenolic-urethanes; release from the corebox is excellent.

Bench life of the mixed sand is several days and sand aged for a few hours actually exhibits strength higher than freshly mixed sand.

Coatings

All core wash types can be applied by the usual techniques.

Coating in ferrous applications is essential in most cases to avoid erosion defects.

Casting Performance

Surface Finish – excellent with non-ferrous castings. Ferrous castings require a coating.

Veining – highly resistant to veining and requires no additives.

Erosion – severe erosion defects can be expected where metal impinges on the core and coating is essential.

Shake-out – excellent.

Gas Evolution – gas-related defects are rare.

Thermal Stability – good resistance to distortion up to early collapse.

Sand Reclamation

Only used as a core process and reclamation is not usually practiced as a unit sand system. Contamination effects in other reclaimed systems are not a problem.

Note: the process is not now widely used but the chemistry is employed in some epoxy-acrylic systems where both curing mechanisms occur. Such mixed systems perform better than either process in isolation (see sulphur dioxide cured epoxy resins).

6.2 Core making Equipment

a) Introduction

There are many manufacturers of coremaking machines throughout the world today, and while they may be referred to as core blowers or core shooters, all core machines with the exception of the shell process, have some components that are common. This is the case whether the machine is a semi-automatic jobbing machine, or the latest high production fully automatic variety – see Exhibit BM.

Mixed core sand is deposited into the hopper above the core machine, and maintained at a specific level by the use of a sensor.

At the start of coremaking, a valve at the top of the blow head is opened to allow a quantity of sand into the head. The level of sand in the blow head is controlled by either an optical sensor fitted above the head, or by a capacitance or other probe resident inside the head.

Only when the valve over the blow head is closed, is compressed air introduced into the blow chamber in order to force the mixed sand into the corebox.

The lower section of the blow head is often called the ‘fishtail’ due to its flared shape. This change in section allows the moving mass of sand to be distributed across the blow plate fitted to the base of the blow head.

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The position and size of the holes or slots in the blow plate will be determined by the configuration of the core being produced. Because of the abrasive nature of the moving sand, the slots or holes are generally steel-lined particularly if the blow plate is made from aluminium, wood or a plastic.

Coreboxes can be made from wood, resin or metal, with the latter being used for volume production. Wood is often used for short runs or development work.

Vents are fitted into the corebox to allow air displaced during blowing and residual blow air to escape from the cavity. It is often not possible to vent all the air due to the use of fine sand, section of core, highly compacted sand, etc. In this case, an exhaust valve connected to the blow head is activated after a pre-set time. This allows any residual air pressure to be vented. Failure to vent this remaining air will result in some sand being carried out with the escaping air, resulting in a poorly formed final core. The gassing operation may be performed by a gassing head placed over the corebox. On this type of machine, the blow head and gassing head are mounted next to each other, and slide along parallel bars. After blowing, the blow head moves to one side for refilling with fresh sand, allowing the gassing head to move over the corebox.

(i) Horizontally/Vertically Split Boxes

The choice between a machine with horizontally or vertically parted boxes will be determined largely by the core to be produced, or occasionally the existing tooling.

A growing number of manufacturers are making machines that are able to operate with either vertically or horizontally jointed boxes for greater flexibility.

(ii) Blow Head Size

Core machines are usually designated by the capacity of the blow head, eg a 25 litre machine. This means that the approximate weight of sand/resin mix held in the blow head will be 30 kg, assuming a density of 1.2 kg/litre. Many sizes of machine are offered today from under 5 litre to 60 litre plus, with the majority in everyday use falling within the 10–40 litre range.

The choice of head size is important if quality cores are to be produced. Whilst it is obvious that the head should, where possible, hold enough mixed sand to produce the cores being made, too large a head compared with the core size will result in weak cores. This is due to the sand/resin mix being subjected to repeated contact with the blow air, thus removing solvents or causing pre-hardening or drying of the resin, dependent on the core binder system being used.

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Many core machines have the facility to double or even triple blow, thereby enabling a machine to be versatile in the range of core sizes produced.

(iii) Core Removal

Removal of cores at its most basic can mean splitting the box and extracting the core by hand. This is not only highly labour intensive, but can also result in broken cores.

Perhaps the most commonly used method of core removal is by mechanically or electrically activated ejectors built into one or both of the corebox halves. On vertically parted box machines, the core is retained inside one half which is turned through 90°. The core is then ejected onto a flat rubber conveyor belt for removal from the machine – Exhibit BN.

A less common method uses a vertical mandrel fitted inside the coreboxes. When the boxes are opened, the core is held on the mandrel which can be advanced to the front of the machine for removal by the machine operator.

On horizontally parted box machines, core removal is often achieved by a mechanically operated 'finger' or removal device which positions itself under the core after ejection from either the top (cope) or bottom (drag) corebox. The device then exits from the machine and presents the core for removal by the operator.

More sophisticated removal of cores can be achieved by the use of a pick and place unit or robot. These devices are able to carry out ancillary operations such as core dressing, dipping and setting.

(iv) Tool Changing

Some machines may be dedicated to producing large volumes of one or two cores, so that the time taken to change boxes is not that important. Where frequent box changes are required, the production downtime must be kept to a minimum.

Rapid box changes can be achieved. Hansberg is one manufacturer that produces a machine that can change not only the coreboxes, but also the blow head if required, in approximately 60 seconds. This is achieved by having the incoming tooling fitted to an arm that rotates about a vertical pillar, on the other side of which is an identical arm fixed onto the outgoing tooling. Hydraulically operated tool clamps automatically position the new box and/or head.

Other manufacturers offer similar machines giving flexibility of operation.

(v) Control and Operating Medium

Hydraulic operation is being used more and more, even on the smaller machines that traditionally used to be pneumatically operated. Hydraulics are now used to give a much smoother operation and produce higher clamping forces, that prevent box opening during the blowing operation.

The rapid development of programmable logic controllers (PLCs) has overtaken other forms of process control as they are able to perform multiple complex control functions reliably.

(vi) Air Impact Core Machines

One core machine that uses air impact is the 'Combi-Core' from DISA, said to act like an extruding machine – Exhibit BO.

While at first glance the operation appears to be that of a conventional core shooter, results to date are said to be superior to those obtained with normal methods.

In this operation the air valve opens rapidly allowing a pre-determined volume of compressed air to impact on the top of the sand column within the blow head. The height of the sand column and the shock wave prevents the air from moving through the sand which reduces the corebox venting requirement. This results in a uniform and increased core density. Although both horizontal and vertical machine formats are available, it is possible to blow a horizontal core with a vertical machine via a 90° elbow attachment.

(vii) Vacuum Operated/Assisted Machines

Similar in operation to some moulding machines, vacuum assisted core machines evacuate air from within the corebox before the sand resident inside the blow head is ejected by the action of the compressed air.

The system proposed by Sintokogio of Japan employs vacuum to draw the prepared sand into the corebox assisted by vibration to the corebox/sand hopper assembly.

The GEN-ATSU method, as it is known (Exhibit BP), is intended for self-hardening or cold-setting core production and so does not require the provision of a gassing head or plate.

Some of the advantages said to be offered by this method are:

- quiet operation
- lower box wear

- wooden coreboxes are possible
- high clamping forces are unnecessary.

b) Mixing Equipment for Core making

(I) Batch Mixers

Twin Blade Horizontal Mixers

The twin blade horizontal mixer is probably the most commonly used type in operation today. This design typically has two shaped mixing blades revolving at approximately 30 rpm to gently mix the sand and resin together.

A sand outlet gate is provided at the front edge of the mixer, operated either manually or pneumatically. A separate discharge gate that forms part of the mill base is fitted to assist when cleaning the mill.

These simple but effective mills are available in the following size ranges: 1-28te/hour.

A variant of the twin blade horizontal mixer is supplied by the German manufacturer, Laempe (Exhibit BQ). Sand is supplied to the mixer bowl by the sand dosing unit in precise quantities as the sand is entering the mixer, the other binder components are also being dosed.

The rotating mixing blade then begins to move up and down through the sand during the mixing cycle to obtain a fully homogeneous mix. It is claimed that this operation causes the sand to heat slightly and therefore reduces the amount of gas or catalyst required during the curing cycle.

When the mixing cycle is completed, the mixing bowl is indexed to one side over the machine, where the sand empties into the blow head or hopper of the core machine.

When the sand has emptied, the mixer bowl undergoes an automatic cleaning cycle utilising a circular steel plate which descends to scrape out any sand residues.

Mixing volumes are 1.5te–5.5te/hour (based on silica sand) with a typical batch time of 1 min 40 seconds.

Vibratory Mixers

A less conventional design is the vibratory batch mixer supplied by Klein of Germany.

In this system, a mixing bowl or chamber is attached to an unbalanced motor, which transmits the vibrations produced into the sand and binder mixture to rotate against guide blades fitted to the chamber wall thus forcing the mixture upwards through a centrally mounted riser tube.

As the mixture overflows as it exits the top of the tube, it creates a closed circulation system which ensures that sand and binder are fully mixed.

When the batch of 15 litres is fully mixed, the stopper in the base of the mixing bowl moves through 90° allowing the mixed sand to empty. It is worth noting that systems using highly viscous binders may be less efficiently mixed using this type of equipment.

The advantages quoted by the manufacturer are:

- a mixing time of only 33 seconds for the 15 litre batch, giving a total batch time of approximately 45 seconds or an hourly output of 2 tonnes
- mixing speed and intensity allows high core strength with low binder levels
- easy removal and cleaning of bowl.

Twin Blade Vertical Mixers

Klein have taken the simple twin blade mixer and turned it through 90° to improve the speed of emptying, component accessibility and better core strengths than conventional twin blade horizontal mixers.

Typical output capacities with silica sand are quoted as 5–9 tonnes per hour depending upon the model used.

The sand mixer is divided into two sections by the fitting of bolts which protrude into the mixing chamber. Either side of the bolts are mixing ploughs which are fitted to the central drive shaft. This design is said to give a highly homogeneous mix by virtue of the sand mass being mixed alternately in each of the mixing areas. The protruding bolts or 'stators' slow the rotational movement of the material, thereby creating several flow paths. The advantages of this design of mixer when compared to other mixers are said to be:

- high mixing intensity
- low binder usage
- reduced cleaning
- good accessibility to all components
- low maintenance.

(ii) Continuous Mixers

The most common design of continuous mixer used in a coremaking facility is the multi-bladed shaft which rotates within a tube.

These blades serve two functions, namely transporting the sand from one end of the trough to the other, and mixing the liquid binder as efficiently as possible with the sand grains. The binder addition is normally made near to the sand inlet point.

There are many manufacturers of continuous mixers whose outputs typically fall within the 1–20 tonnes per hour output range. However, attention should be paid to the design of the mixer, to ensure it gives consistent and efficient mixing and to ensure ease of maintenance.

c) Odour Removal

The ever more stringent environmental regulations being introduced to curb emissions to the atmosphere, demand attention as to how the by-products of core manufacture are treated. Whether it is the recognisable fishy smell of the phenolic urethane process or the unpleasantness of a sulphur dioxide based system, the gases bearing these odours need to be processed correctly, to limit their emissions to atmosphere.

Early in the life of cold box binders, attempts were made to mask the smell of the amine catalyst by injecting sweet smelling perfumes into the waste gas extraction system. Unfortunately, the two odours, once outside the building, disassociated because of their different molecular weights.

The problem has been resolved by using gas-fired after-burners or odour incinerators. Whilst these have proved successful, they do entail the use of large amounts of energy.

The most successful method of odour removal is by gas scrubbing, which forms part of the air extraction equipment. This involves passing the alkaline amine vapour through an acidic liquor, causing a chemical exchange to take place, removing the unwanted smell.

Two forms of gas scrubber are in common use today:

- packed bed
- impingement plate.

(I) Packed Bed Scrubber

The packed bed design, as seen in Exhibit BR, pumps liquor from the base of the tower up through spray bars and over the packed bed. The bed, which is comprised of multi-faced plastic discs, affords a high surface area on which the chemical exchanges take place.

A mist or spray eliminator is fitted at the top of the tower in order to remove any entrained water droplets from the escaping gases

Contaminated air from core machines is usually extracted at a minimum rate of 3500m³/hour, dependent on the size of machine. This figure is often exceeded by many foundries in the interest of operator comfort.

Packed bed scrubbers normally operate on an internal gas velocity of between 1.5 and 3.6 metres/second to obtain maximum operating efficiency.

(ii) Impingement Plate Scrubber

The design varies from the packed bed type only in the method of gas/liquor interaction. Figure 62 shows an enlarged detail of a section of the impingement plates fitted inside the tower which is shown in Exhibit BT.

Air extracted from the core machine is drawn up into the spray section below the impingement plates. This spray section removes large particulate in the air stream. This design of gas scrubber is tolerant of dust in the extracted air compared to the packed bed design which is not.

As the air passes through the holes in the plate, the velocity increases causing the stream to hit the 'L' shaped baffle at high speed. This causes some atomisation of the gas which produces minute gas bubbles in the liquor being carried over the impingement plate, therefore giving a high surface area for the chemical exchange to take place. The liquor also removes any further particulate remaining in the airstream.

Airstream velocities of between 2.1 and 2.5 m/s are normally used.

In either design, the chemical employed in removing the odour is the same. For amine, phosphoric acid or sulphuric acid would be used. Both give similar results, although sulphuric acid is much cheaper than phosphoric.

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In order to maintain effective gas odour removal, the pH of the liquor must be maintained between close limits. For amine systems this would be between 2.0 and 2.5. The most satisfactory method of achieving this is by automatic dosing of the liquor, which takes place when submerged probes detect an increase in pH in the system.

For binder systems using sulphur dioxide, the scrubbing medium used would be sodium hydroxide, or less commonly, hydrogen peroxide.

Shell core processes can produce both acidic and alkaline pollutants, therefore a two stage scrubber would need to be employed.

Other less commonly used methods of odour removal include activated carbon beds or biological scrubbers.

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Exhibit BJ Core processes in use

Cold Box	No-Bake	Heat-Activated
Phenolic/Urethane/Amine	Furane/Acid	Shell
Silicate/CO ₂	Phenolic/Acid	Oil Sand
Furane/SO ₂	Phenolic/Ester	Phenolic Hot Box
Epoxy/SO ₂	Oil Urethane	Furane Hot Box
Phenolic/SO ₂	Silicate/Ester	Warm Box
Phenolic/Ester	Phenolic Urethane	
	Alumina Phosphate	

Exhibit BK Application of hot box cores

	UF	UF/FA	PF	PF/FA	PF/UF	PF/UF/FA
Metals Cast	Plumbers brass and non-ferrous especially thin section tap wear	Ferrous, malleable, non-ferrous, aluminium	Low carbon steel, malleable iron, SG iron	Low carbon steels, iron (dependent on nitrogen content)	Grey iron, malleable iron, aluminium	Iron/non-ferrous (specialist applications)
Surface Finish	Good but dependent on sand AFS and whether refractory coatings used					
Penetration	Good resistance but is dependent on sand AFS and whether coatings used					
Burn On	Unlikely	Not a general problem	Possible	Small possibility	Possible but low risk	Possible but low risk
Mould/Metal* Reaction (Pinholing)	Not usual	Not usual	Not usual	Not usual	Not usual	Not usual
Erosion	Yes, but dependent on gating	No	No	No	No	No
Breakdown	Excellent	Excellent	Good	Fair	Good	Good
Hot Tearing	No	No	Possible	Not usual (plasticisers can be used)	No	Not usual (plasticisers can be used)
Finning/Veining	No	No	Yes	Yes	Possible**	Possible**

* A binder of the correct Nitrogen content for each metal cast is essential.

** Up to 3% Iron Oxide can be added to the sand to avoid finning. This also reduces pinholing.

Exhibit BL

Water reaction with MDI

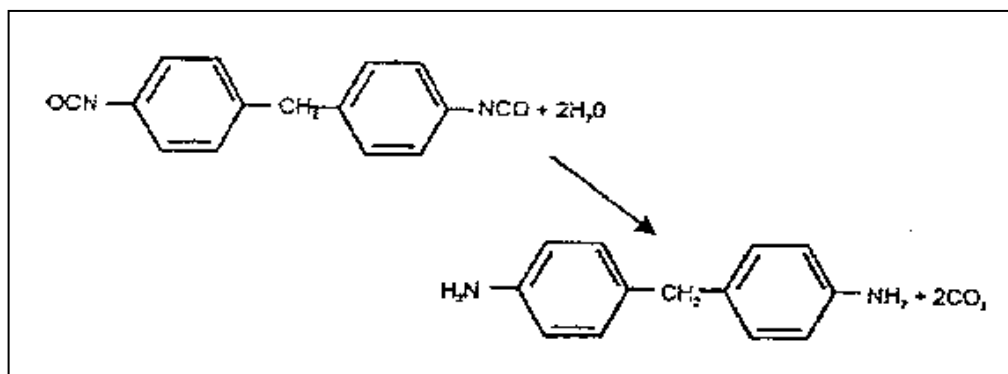


Exhibit BM

Components of a typical core machine

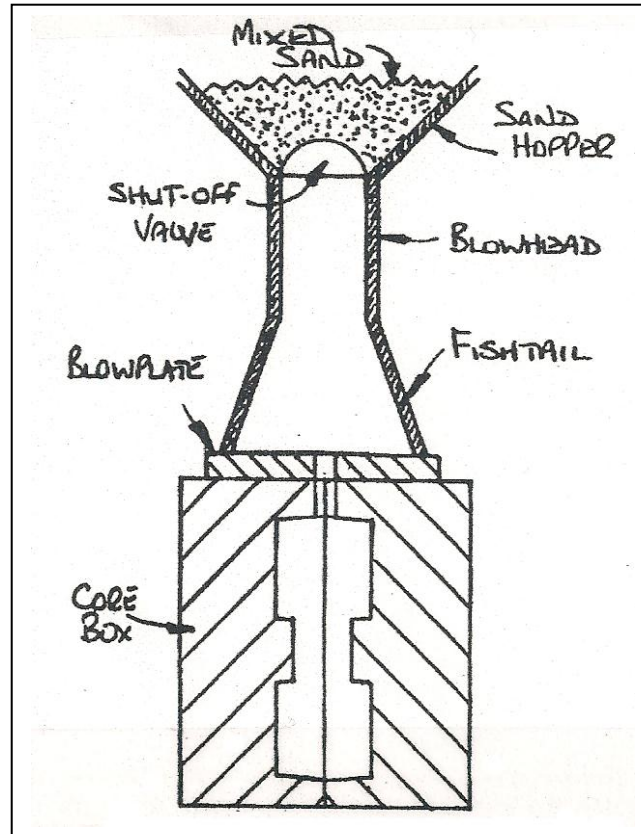


Exhibit BN

Core removal

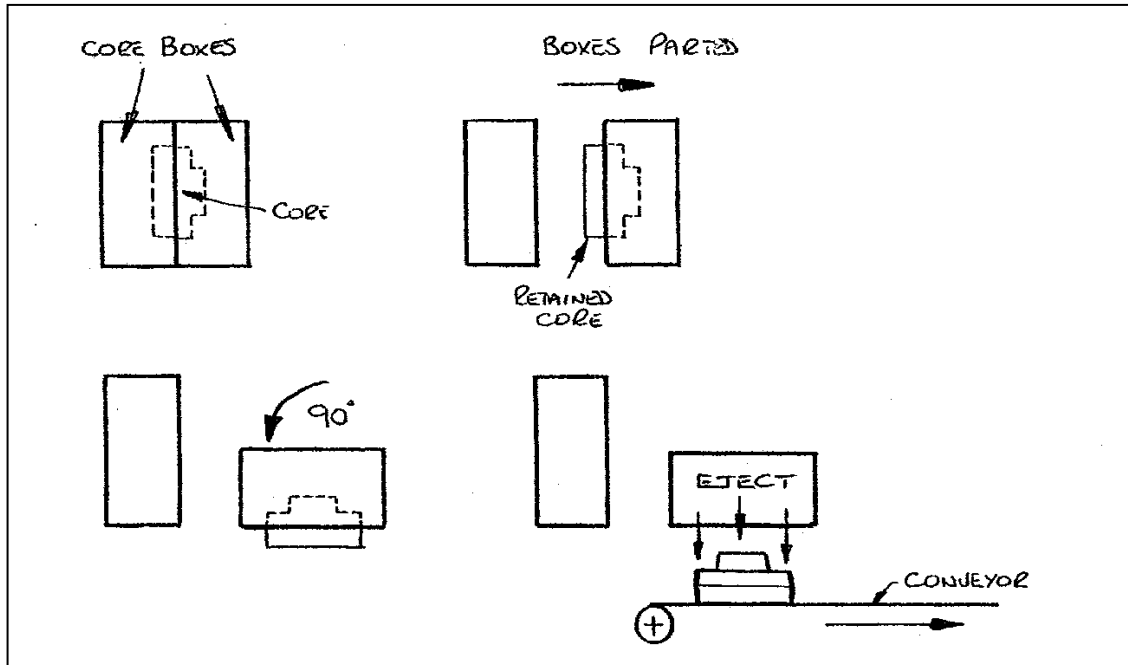


Exhibit BO

Air impact core machines – sequence of operations

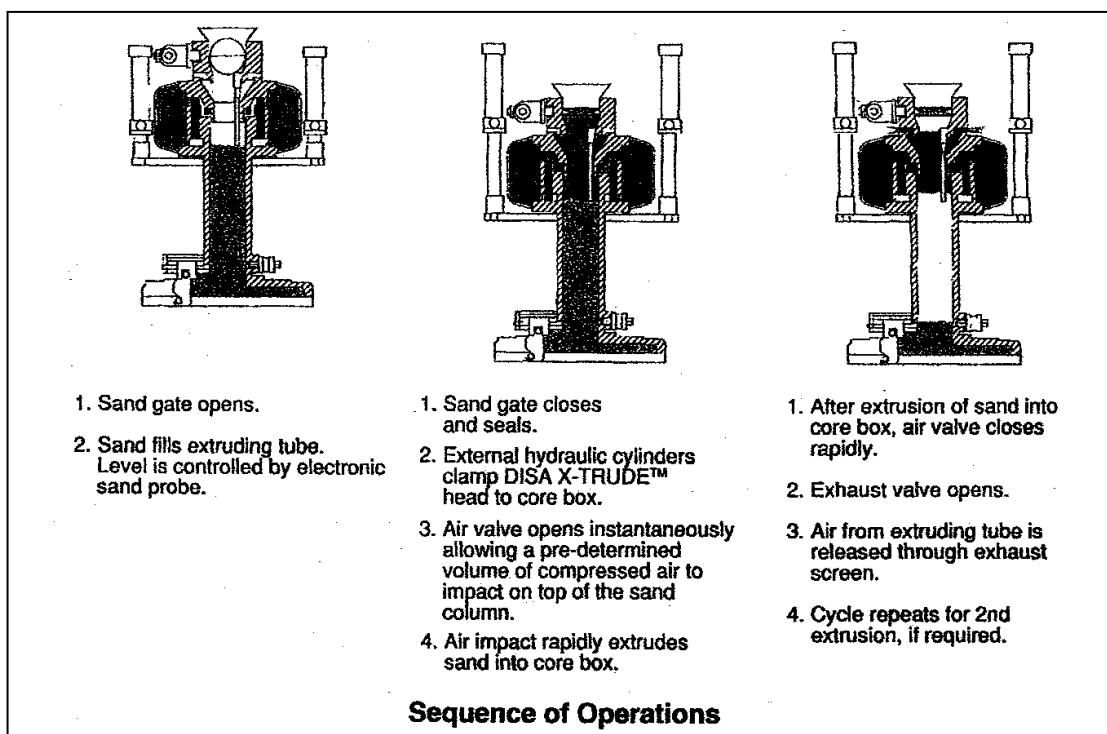


Exhibit BP

GEN-ATSU sand compaction method

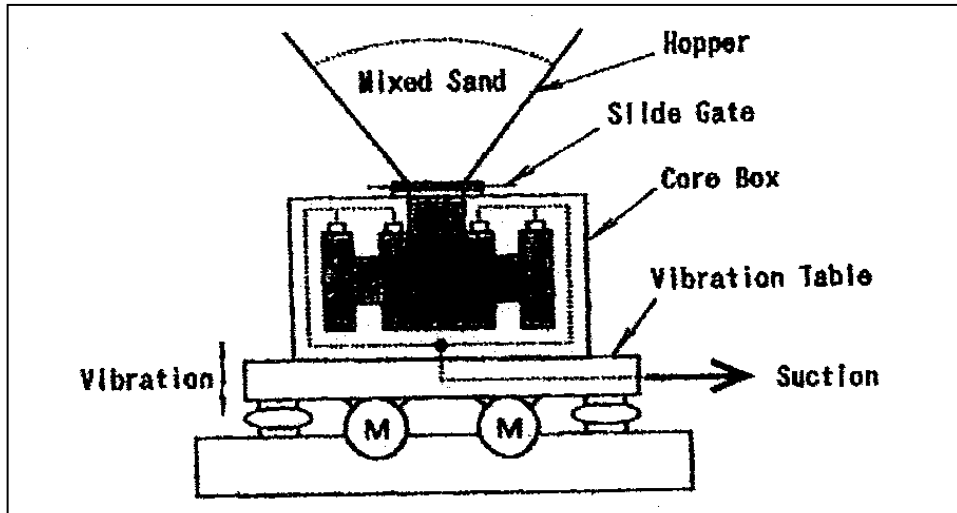


Exhibit BQ

Laempe mixer

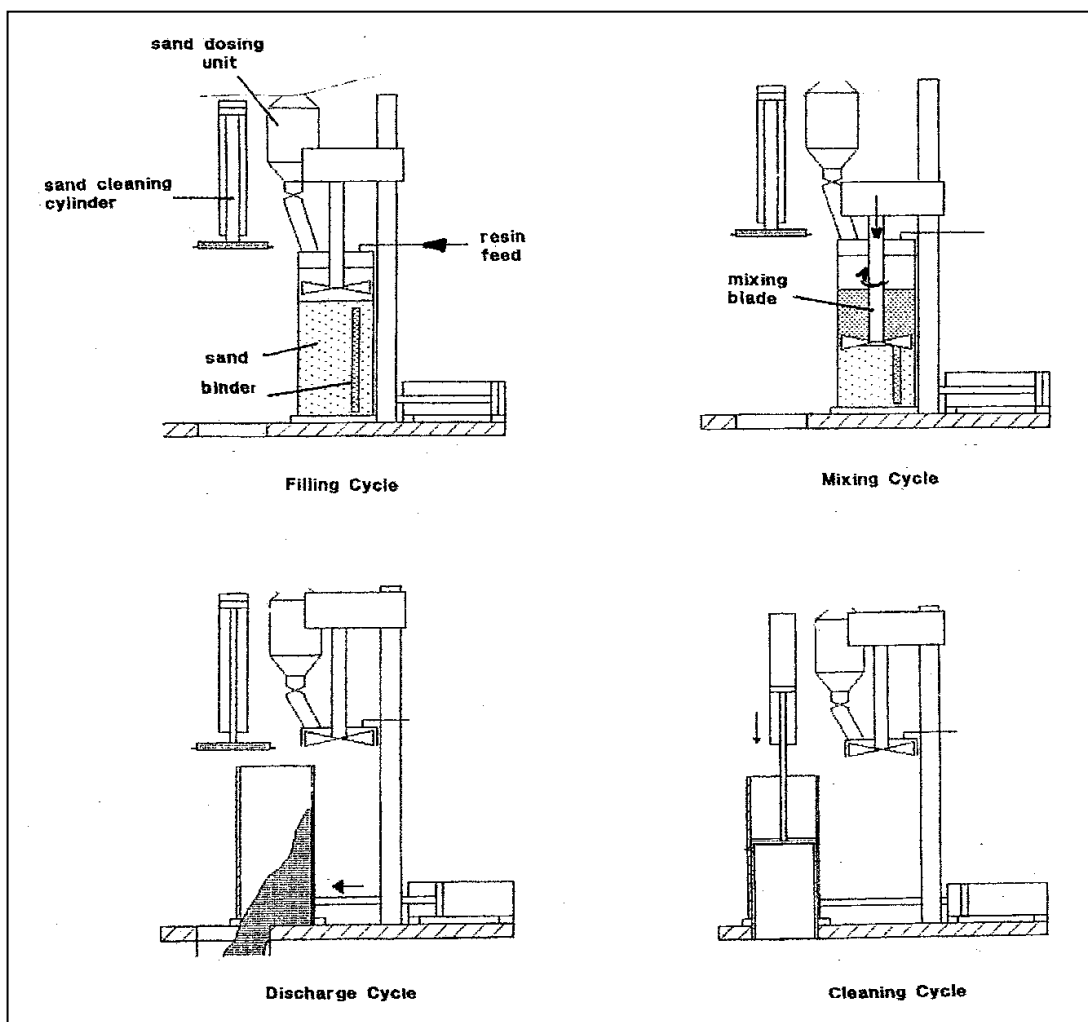


Exhibit BR

Packed bed scrubber

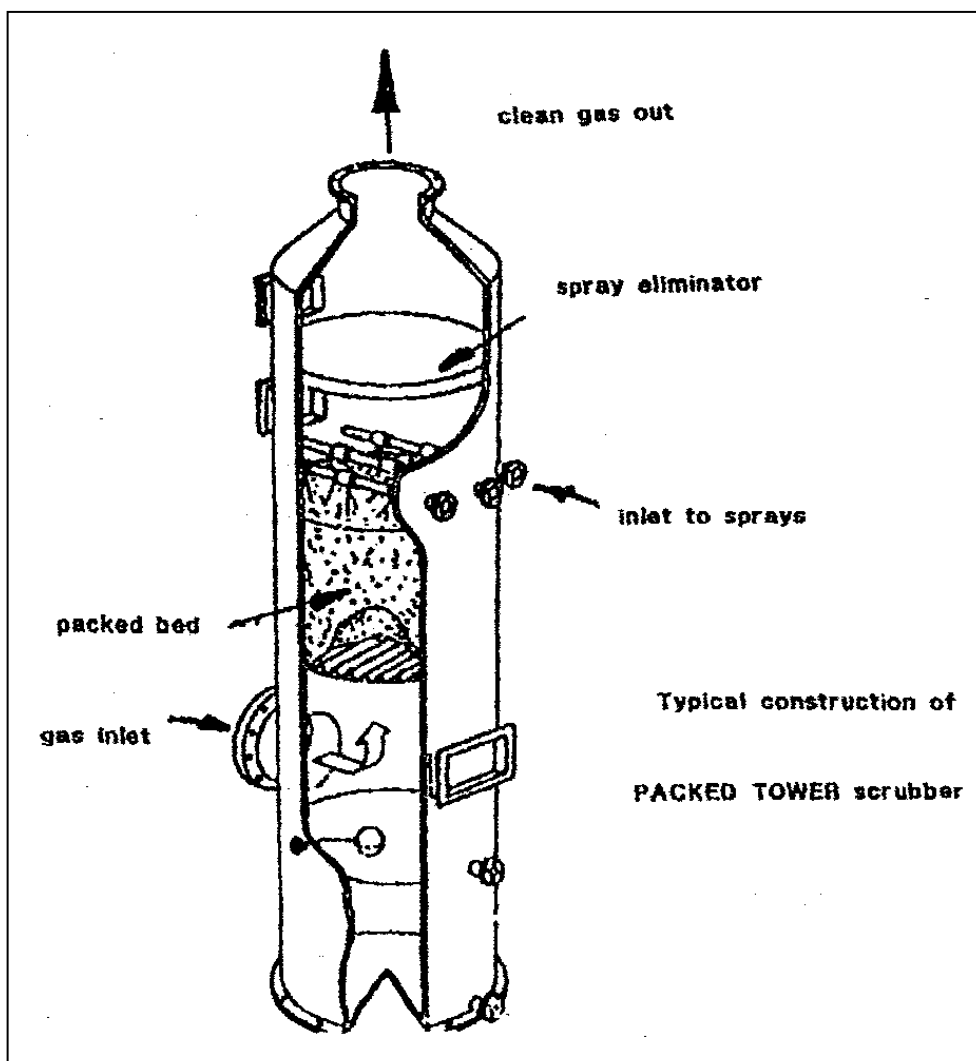


Exhibit BS

Impingement plate scrubber

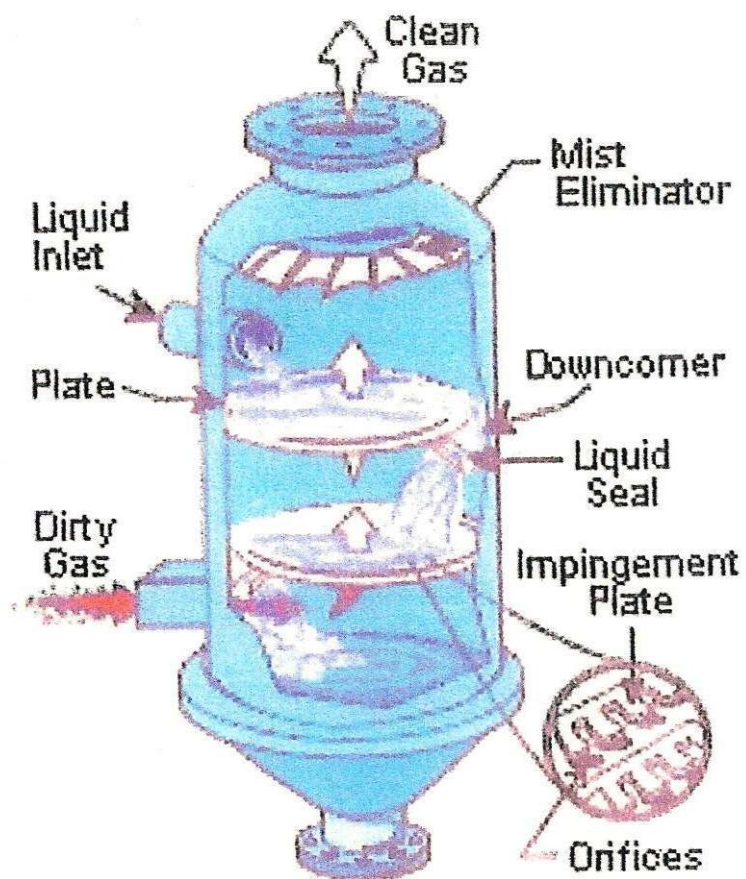
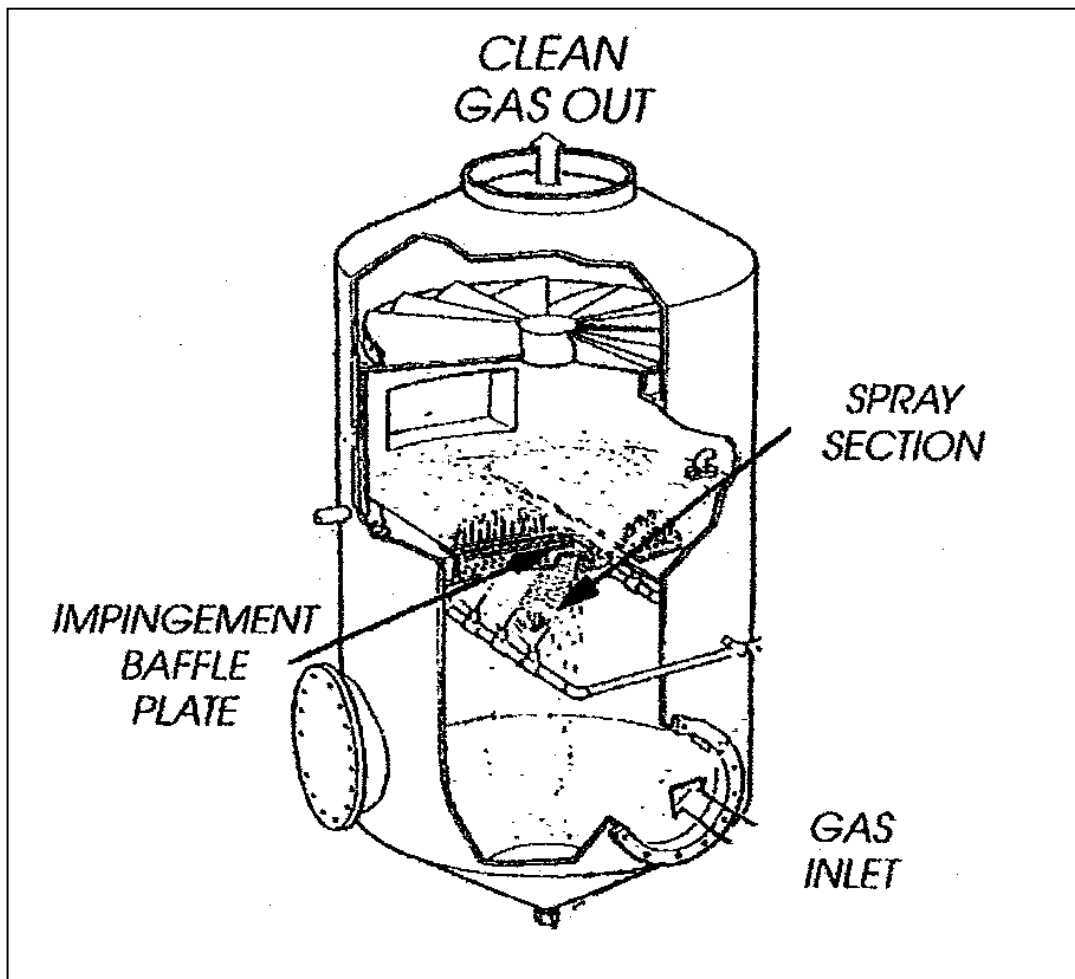


Exhibit BT

Impingement plate tower



7.0 COOLING AND SEPARATION

7.1 Casting Cooling

After pouring and solidification, the castings then have to cool before any further processing can take place. The castings are cooled in two ways:

- a) in the mould package
- b) out of the mould.

a) In-Mould Cooling

The cooling track of the moulding line should have sufficient cooling time, at the line operating speed, to allow the castings in the mould package to cool to a pre-designed temperature. This temperature must be low enough to prevent any unwanted metallurgical changes taking place on knock-out and to allow the next stage of the manufacturing process to take place.

The length of the cooling line required is derived from two components:

- the target temperature of the castings
- the casting modulus.

The casting modulus represents the relationship between the surface area and volume of the casting and hence the heat transfer characteristics.

A cooling line that is too short will cause problems with casting quality, whereas one which is too long will represent a much higher capital cost.

b) Casting Cooling Outside the Mould

A compromise on length of the cooling line is to knock out castings at a higher temperature and then cool them further out of the mould before moving on to the next process. There are three basic ways to achieve this additional cooling:

- a) natural cooling
- b) forced air cooling
- c) cooling during casting/sand separation process.

7.2 Casting/Sand Separation

After in-mould cooling it is necessary to separate the casting from the moulding sand. The traditional method of doing this involved some form of vibrating mechanism. Over the past few years other methods of separation have gained favour, especially amongst the high volume foundries.

a) Rotary Drum

Although individual manufacturers' designs vary slightly, all are basically a large slowly rotating drum that has an inner perforated cylinder through which sand can fall as it is stripped from the casting. As the sand exits from the drum it is returned to the sandplant for cooling and reconditioning.

A good example of this design of drum is produced by the Didion Manufacturing Company. The forward motion of the castings is effected by the fitting of cast helical ribs. Retention time of castings within the drum is determined by the angle of those ribs and the variable rotational speed of the drum, and also the angle at which the drum is set.

As can be seen in Exhibit BU, the reverse side of the perforated liner has an additional set of helical ribs or blades. The angle at which these blades are set dictates whether the sand exits from the drum at the mould inlet end or the casting exit end. It is also possible to fit blades that can discharge at any preferred location along the drum length. This feature accords greater flexibility when designing a new installation or adding the drum to an existing operation.

b) Vibratory Drum

This continuous process consists of a stationary drum, which can be from one to four metres in diameter, and up to 18 metres long, and which vibrates on one side only. The vibration, being provided by out-of-balance motors and amplified by exciter springs, induces the sand and castings to migrate up one side of the drum in a circular motion – Exhibit BV.

Movement through the drum is obtained by setting the drum assembly at a small angle – typically around 2–3°.

Castings and sand exit from the same end, either as one mass in the case of fragile components, or separately with the sand falling through a perforated screen.

Because of the gentle folding action created in this design of separator, it is particularly suitable for delicate work.

The folding action is also effective in cooling the castings, provided moisture is present in the sand and air is extracted from the drum.

c) Vibratory Shake-Outs

The traditional method of separating the casting from moulding sand, and dependent on the core system used, the removal of the internal core sand.

It is important that the shake-out operation is employed only when the casting has solidified sufficiently to ensure that damage will not result from the passage through the shake-out machine.

The vibration imparted to the shake-out deck can be linear rotational, or elliptical in motion. The frequency and stroke are designed to suit the particular range of castings being processed.

The source of the vibration can be either single or multiple rotating masses attached directly to create a brute force system or indirectly to create a natural frequency system.

Brute force drives can be out-of-balance weights on the end of rotating shafts driven by electric motors.

The natural frequency drives also use adjustable out of balance weights fitted to an electric motor. But this vibration is amplified by springs to produce the desired vibration with lower power and cost.

7.3 Sand Cooling

a) Introduction

The cooling of moulding sand is a necessity in most foundries if problems at the moulding machine are to be avoided. The degree of cooling required will vary from one foundry to another. A sand temperature of around 60°C at the moulding machine may be acceptable for some operators, while at another foundry any sand over 40°C will result in poor stripping from the pattern.

Cooling by air alone is not very efficient, it is only when added moisture is evaporated from the sand that effective cooling is achieved. The standard rule of thumb is for every 1% of water evaporated from the sand, a reduction on temperature of 26°C can be expected.

With sand temperatures above 100°C, cooling is simple as long as there is sufficient moisture in the sand, this immediately flashes off into steam.

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Below this temperature it becomes more difficult to cool the sand. Exhibit BW illustrates the problem. As the temperature reduces the ability of air to absorb moisture reduces along the line shown, this is known as an asymptotic curve.

As can be seen, the available heat content of the air below about 45°C is quite low, therefore to achieve cooling below this point larger and larger volumes of air are needed.

It should be noted that as the temperature of the sand falls, the quantity of the water added to the sand to achieve further cooling must be carefully monitored. If this is not done, the excess moisture may cause problems such as sticking in the storage hoppers, etc.

There are many specialised designs of equipment available today that will give good results in cooling sand and this section attempts to explain their relative merits.

b) Rotary Cooling Screen

This common item of plant can, with perhaps a few minor modifications, give excellent cooling results.

The rotary screen may be cylindrical or hexagonal in section, parallel or tapered. All will achieve evaporative cooling by the process of drawing air through the falling sand in the screen body.

Exhibit BX shows a schematic diagram of a typical rotary cooling screen. Extraction velocities through the plan area of the screen cage should normally not exceed 0.75 metres per second if removal of fines from the sand is to be avoided.

When sizing up the extract ducts from the screen canopy, a velocity of around 18 metres per second should be used in order to prevent dust particles in the air stream dropping out of suspension.

Exhibit BY shows a chart recorder trace from an actual cooling screen in operation. The unit was designed for the purpose and handles on average of 120 tonnes of sand per hour.

In order to calculate the efficiency of the cooling screen, the following calculation is generally used:

$$\frac{\text{Inlet temp} - \text{Outlet temp}}{\text{Inlet temp} - \text{Ambient temp}} \times 100$$

Using this formula, it can be seen that the efficiency of this particular screen is around 55%. This figure is higher than is normally expected, but is due to the attention to moisture addition before the screen and a high air extraction rate through it.

c) Fluidised Bed Cooling

A vibrating screen bed through which air is blown is the basis for this design of cooling plant – Exhibit BZ.

Sand is delivered onto the screen in a controlled manner in order to maintain a constant depth. As the sand is transported across the screen bed by the vibratory action, the air from the cooling fan fluidises the sand and allows evaporation of the entrained moisture.

It is important that the moisture level is not excessive or this will result in the blocking of the screen bed. Equally, too dry a sand can cause over extraction of fines from the sand. These two points have in the past made the fluidised bed cooler an unpopular piece of equipment, but the latest designs available today pay particular attention to the delivery of moisture consistent sand.

Sensors in the unit prevent water being added to already moist sand, and when low levels of sand are passing through.

d) Vertical Tower Cooler

Sand, on to which a measured amount of moisture has been added, falls through a rotating screen in an even flow onto a bed of fluidised sand – Exhibit CA.

Air is blown into the bed of sand via tubes from a central manifold causing the sand to be fluidised and therefore releasing the heat within the sand through evaporation.

The air moving upward passes through the falling sand to achieve maximum efficiency.

It is essential to maintain the correct bed depth in order to obtain adequate fluidisation, and this is achieved by the operation of the discharge belt.

Models are available to process between 15–240 tonnes per hour. Quoted cooling range is from 100°C inlet temperature down to 40°C outlet sand temperature.

e) Cooling Drums

Cooling drums usually form part of the casting/sand separation area of the sandplant and, as such, are normally sited at the end of the moulding line.

The cylindrical drums are set at an angle of up to 10° to the horizontal and slowly rotate enabling the sand and castings to separate and tumble without damage, it is claimed.

Air is extracted from the drum to remove the dust and moisture laden air.

As the castings and sand migrate towards the exit end, the sand falls through a perforated section of the drum to be returned into the sandplant.

Because of the constant contact with the hot castings, heat is transferred into the sand. This means that this type of plant is more suitable for the cooling of the castings rather than reducing the temperature of the sand.

f) Bucket Elevators

Bucket elevators form a standard part of many sandplants and can provide a means of achieving some cooling of the sand. By extracting air from the top of the elevator casting some removal of heat is possible, dependent upon the moisture content within the sand. If moisture is not present, cooling will not take place and excessive removal of fines from the sand may occur.

To achieve good cooling from this type of equipment, the control of water addition to the sand is normally effected by the incorporation of a mixer sited at the base of the elevator.

Sand fed by conveyor into the mixer is continually monitored for temperature. Water is then added into the mixer as necessary.

g) Cooling Sand in a Batch Mill Using Vacuum

A schematic diagram of the equipment is shown in Exhibit CB. It comprises a batch mill of the counter-intensive type connected to a vacuum pump and condenser.

In operation the cooler mixes the batch sand for a short time to achieve homogeneity before sampling the moisture content and the temperature of the sand. An addition of water is made based upon the quantity of heat to be lost and the final desired moisture level.

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The pressure in the mixer is then lowered via the vacuum pump. As the internal pressure is reduced, the moisture in the sand begins to evaporate.

The vapour is condensed and the resultant liquid is used for water additions to subsequent batches.

Heat generated by condensation is removed by a heat exchanger which would be connected to a closed circuit cooling system.

The operating principle of the cooler is that the boiling point of water is reduced as the atmospheric pressure reduces.

The relationship between pressure and temperature is shown in Exhibit CC.

Using the vapour pressure curve for water, as shown in Exhibit CD, it can be seen that any rise in the water partial vacuum pressure above the equilibrium pressure of a cold surface will result in condensation.

In the graph shown in Exhibit CE, we are shown a typical example of a batch of return sand at 85°C at an ambient air pressure of 1013 mbar (Point A).

As the pressure is initially lowered, the temperature does not change, but as soon as the vapour pressure curve reaches Point B, the water in the sand begins to boil and thus evaporates the heat from the sand. This process continues until the pressure evaluation is stopped at 56 mbar at Point C resulting in a final sand temperature of 35°C.

It may be assumed from the foregoing that the process is a time consuming one, yet as the time diagram in Exhibit CF indicates, it takes no longer than 180 seconds for the full cycle.

This method of cooling does have the advantage of reducing the temperature of the sand without the need to extract large volumes of air and the associated equipment required, with the potential loss of fines with this method.

h) Slow Running Conveyor Belts

Finally in this section the ability to use slow running conveyor belts as an effective method of heat removal should not be overlooked. By insertion into the sand burden of 'disturbers' or turnover devices, a great deal of cooling can be achieved, especially in the higher temperature bands.

Exhibit BU

Rotary drum

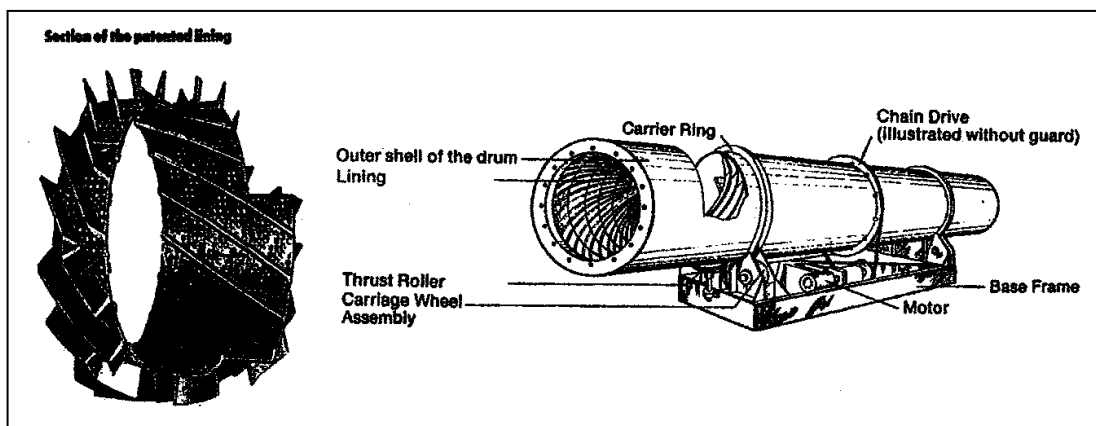


Exhibit BV

Vibratory drum

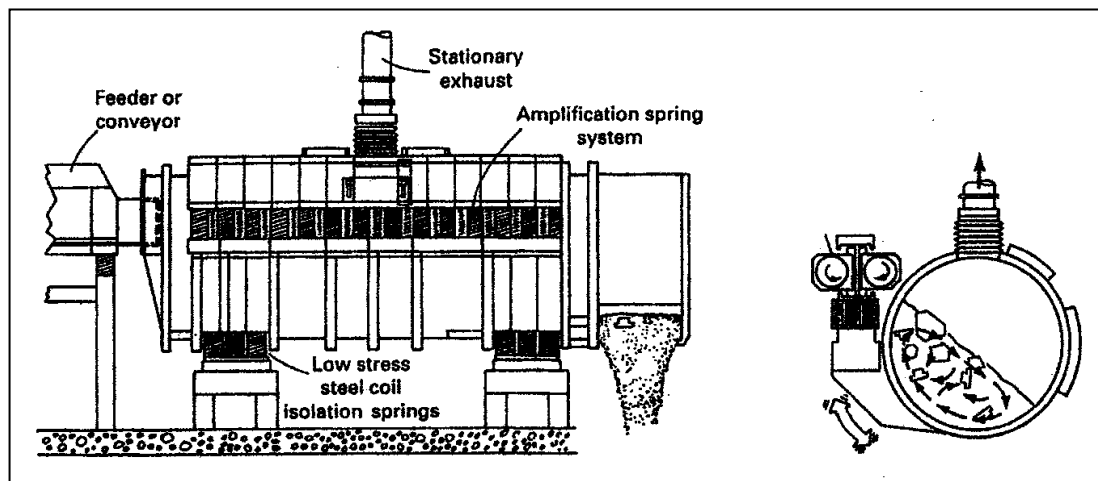


Exhibit BW

Relationship between temperature and moisture absorption in air

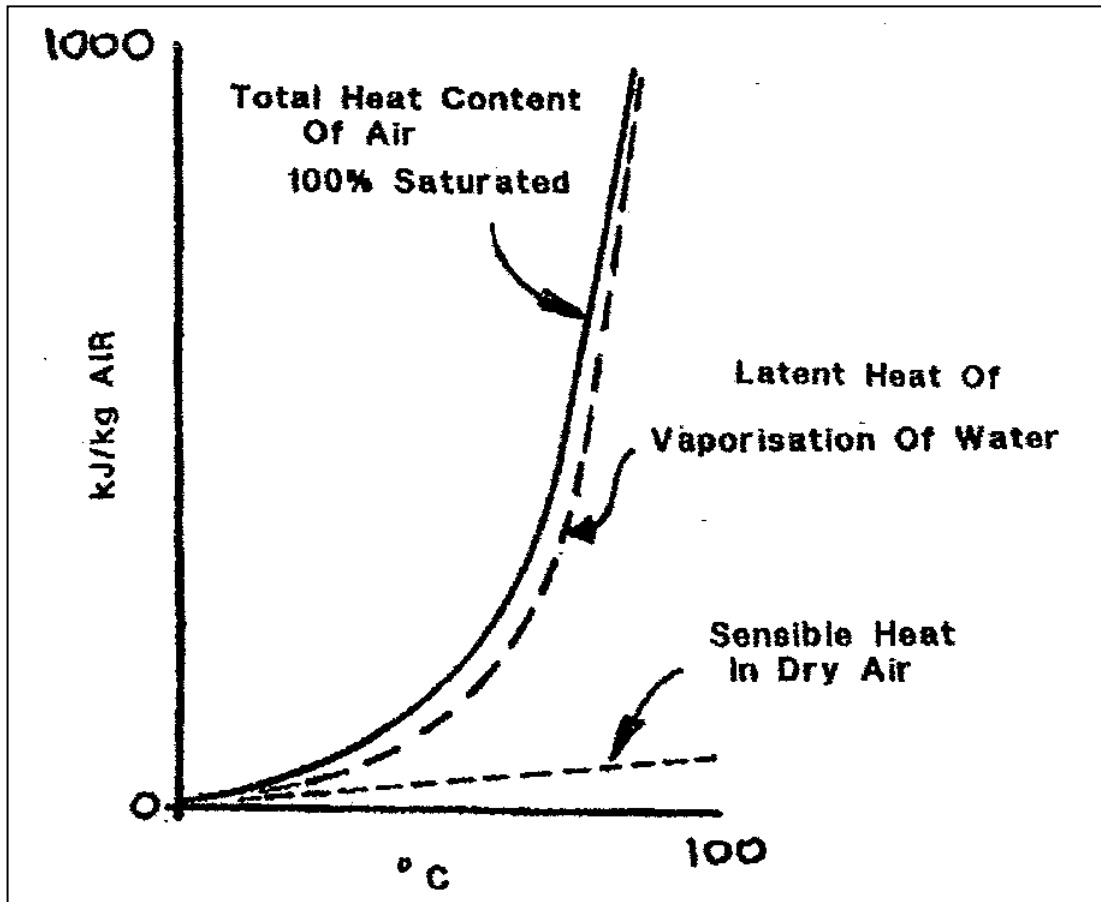


Exhibit BX

Main elements of a rotary cooling screen

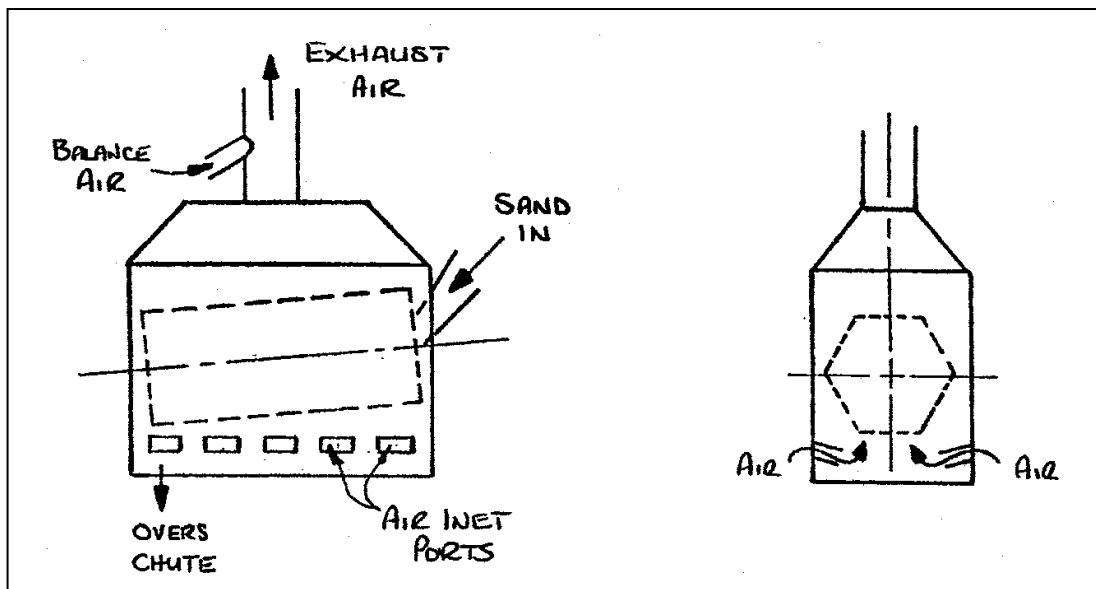


Exhibit BY

Cooling screen temperature trace

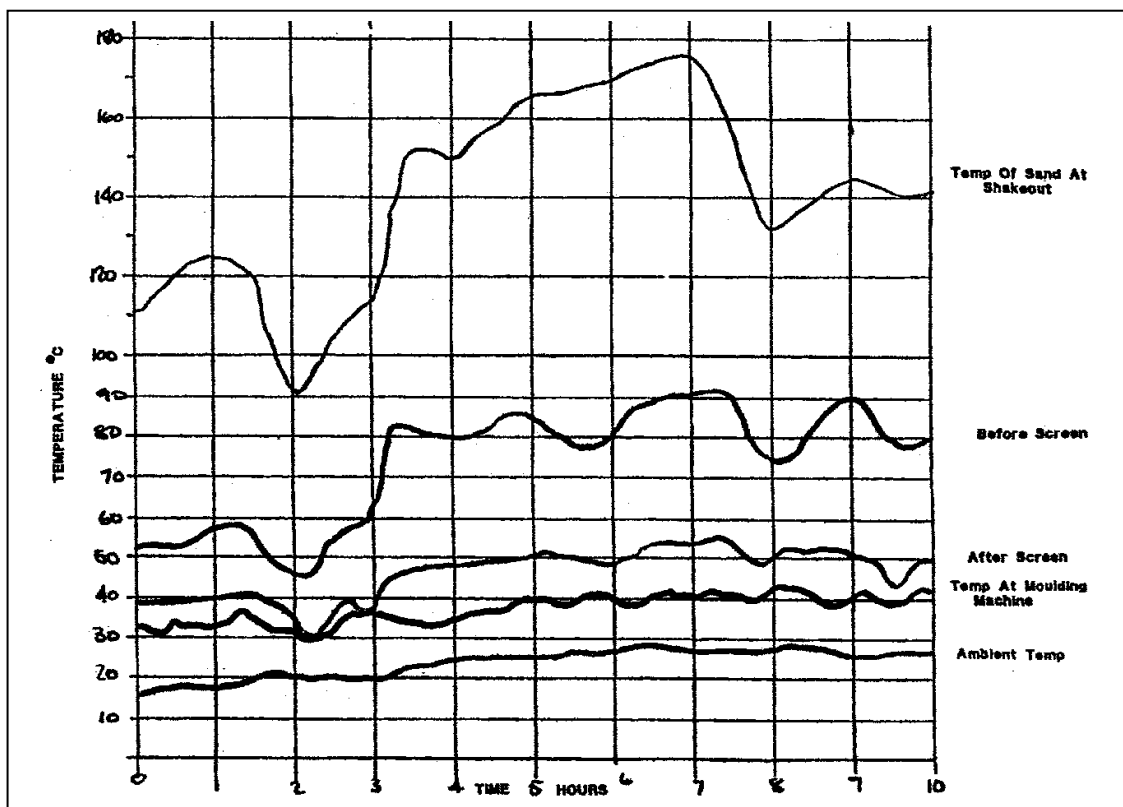


Exhibit BZ

Basic elements of a fluid bed cooler

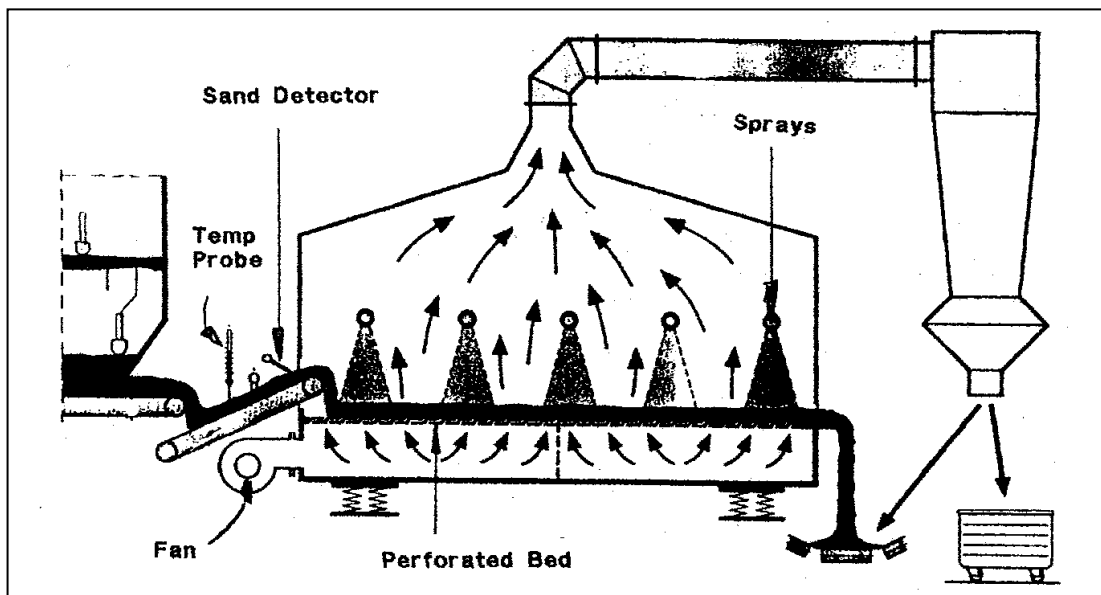


Exhibit CA

Vertical tower cooler

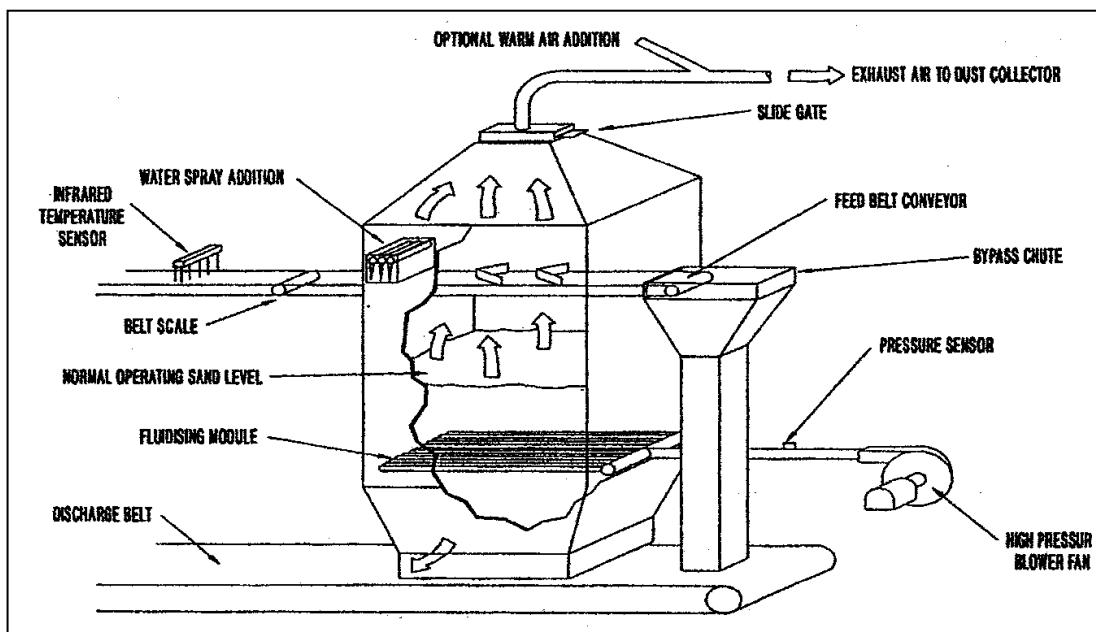


Exhibit CB

Schematic diagram of a vacuum cooling system for moulding sand

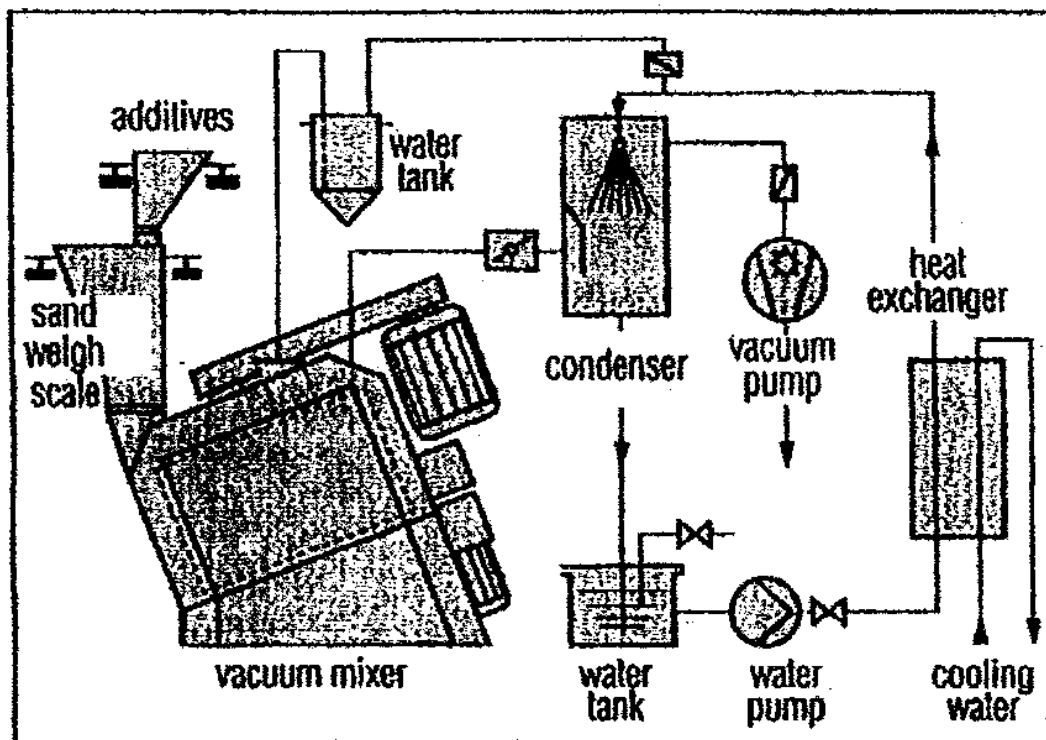


Exhibit CC

Pressure v/s temperature

p in mbar	t in °C
10	6.98
50	32.90
100	45.83
300	69.12
600	85.96
1000	99.63
1100	102.32

Exhibit CD

Vapour pressure curve for water

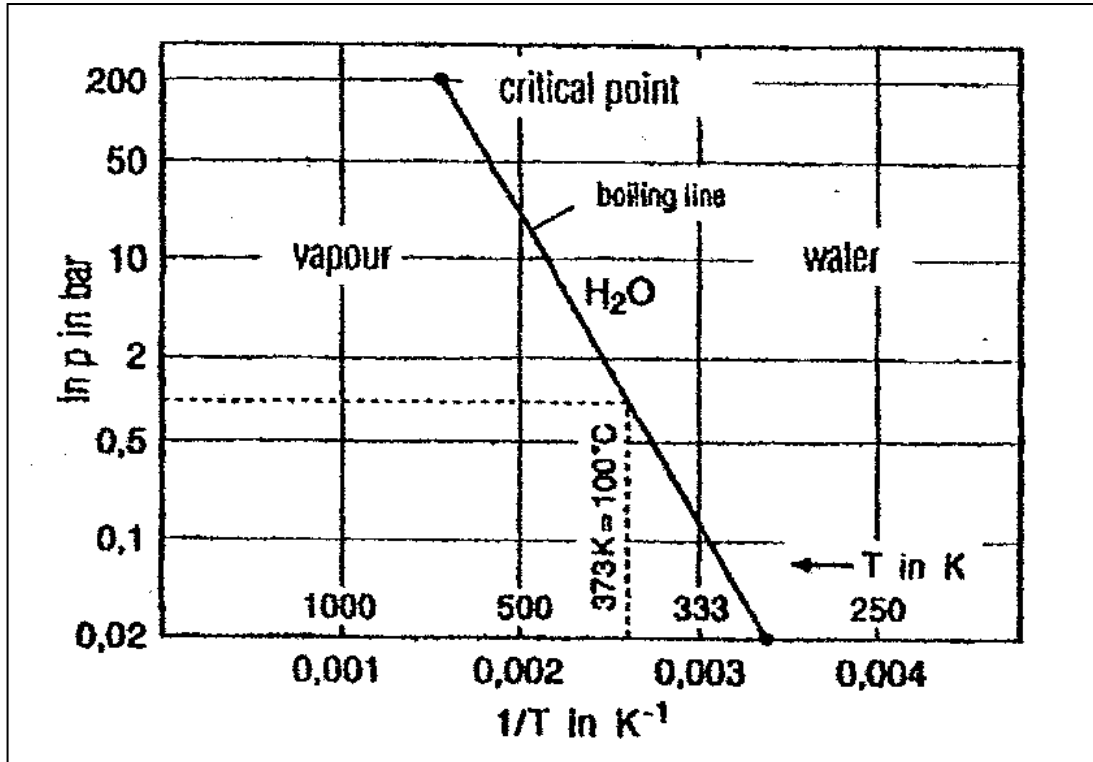


Exhibit CE

Pressure/temperature diagram for water

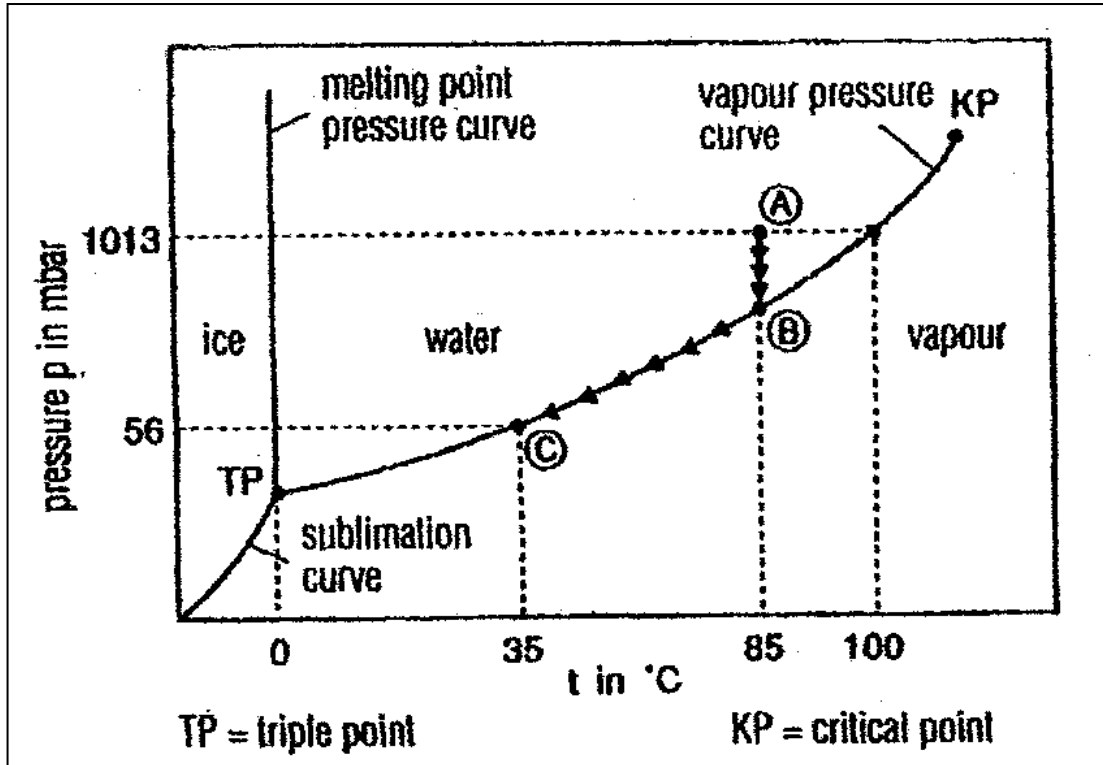
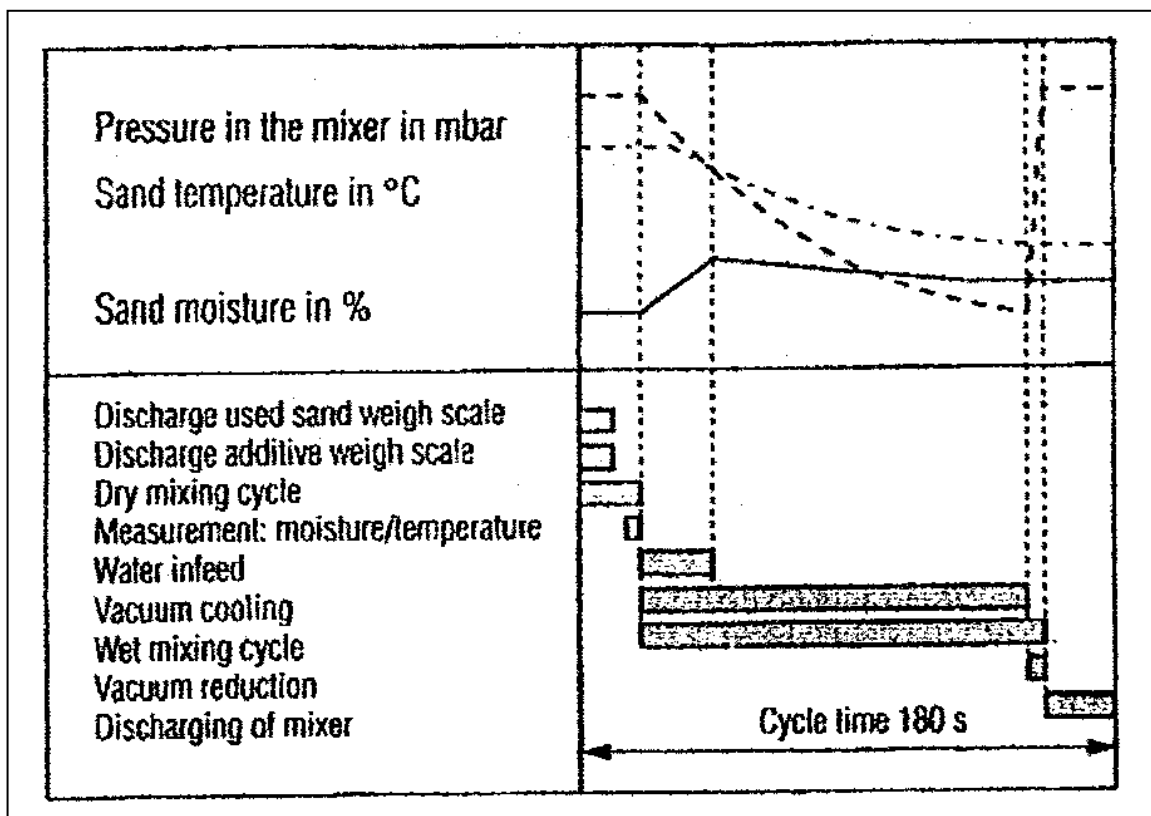


Exhibit CF

Time diagram – moulding sand cooling in a vacuum mixer



8.0 FINISHING

8.1 De-Sprueing, Grinding and Fettling Castings

a) Feeder Removal

Metal removal operations such as the removal of runners, risers and pad areas, can represent a significant portion of the total manufacturing cost. The key to finding economies in this area is close interaction with the methods department to design optimum feeder head necks and gating systems and to reduce contact area of feeders with the castings to the optimum.

The most common systems for feeder removal in the order of increasing cost in steel foundries are:

- **Simple break off.**
- **Flame cutting** – this method removes gating and risers from steel castings. Pre-heating of the casting causes ignition of the O₂ and the subsequent melting of the target metal, and is used with an oxygen lance for cutting appendages from large castings.
- **Air carbon arc cutting** – widely used to replace some grinding and chipping operations, it is one of the most economical methods for removing excess metal. Heat is generated by the electric arc created between a copper-coated, carbon-graphite electrode and the casting. The arc-air operation process has widespread application in medium to large castings, other than those subject to heat cracking. It removes metal rapidly and at best precludes the need for further grinding. Its main disadvantage is noise and fume generation. A good design is to have the process carried out in an environmentally controlled booth complete with a well designed handling system.
- **Abrasive cut off/grinding wheels** – wheels are among the fastest ways to clean up any metal casting. They use abrasive-coated or bonded wheels to remove large appendages and reduce pads or surface flaws. Economical abrasive wheels are mounted on swing frames suspended from bridge cranes (for use on castings too large to manipulate). Abrasive wheel cutting should be carried out using jigs and fixtures to obtain an accurate cut, to avoid further grinding and shot blasting.
- **Thermal torching** – used for cutting heavy risers, thermal torches use steel, aluminium and magnesium alloy rods and high-velocity oxygen to create a high temperature burn. The torch creates a kerf, or slot, that is easily controlled by the operator. Cutting speed is based on the velocity of the oxygen stream and nozzle

size. Low velocity oxygen torches are used as gougers to remove small defects more effectively than chipping (particularly in confined spaces) and for scarfing, or reducing large pads using medium velocity oxygen and a large nozzle.

In cutting off runners, risers and ingates, removal should always occur as close to the casting as possible where alloy and section thickness will allow, to reduce or eliminate grinding in this area. Gates, runners and risers may be designed with notches to help streamline cutting operations. It is also important that the area where the ingates are attached to the casting be designed in a rectangular section to improve the break-off potential through the thin section of the rectangle.

b) Dressing of Castings

(i) Reasons for Dressing Castings

On release from the mould a casting is rarely, if ever, in a satisfactory condition for immediate despatch to the customer. After cleaning it will normally require some dressing before it is acceptable to the customer and the amount of work required will depend on the customer's requirements and the method of production.

Minimising the amount of dressing required should be the aim of every foundry, but the overall cost of achieving the desired result must become the overriding factor. For example, the production of turbine blades by investment casting requires very little finishing, but the cost of producing an engineering casting, say a lathe bed, by this method would be prohibitive.

Again, a casting is no better than the pattern from which it is made and a large volume requirement could justify expensive metal pattern equipment, but an order for a few off would warrant a much cheaper pattern, even if it necessitated more dressing.

Where heat treatment must be carried out, as for malleable iron, a straightening operation is often necessary to correct distortion. The use of carriers in the heat treatment ovens may reduce this, but the relative costs are usually in favour of the pressing operation.

Meeting customers' specifications is the deciding factor in dressing, but the production facilities available to the foundry will dictate the amount necessary in order to produce in the most economic manner.

The as-cast casting, having been cleaned by shot blasting or a similar method, reaches the dressing shop and:

- a) may have varying degrees of flash around the joint line or core prints which require trimming;

- b) if ductile as-cast, feeders normally remain which require cutting off;
- c) excess material, such as feeder pads, gates, risers, ties and cracking strips will have to be removed;
- d) certain cosmetic operations may be required to correct the following faults:
 - rough surface finish
 - ram off
 - finning
 - swelling
 - metal penetration
 - sand inclusions
- e) where heat treatment has been carried out, a straightening operation may be necessary.

Thus the amount of dressing required will depend on the production facilities available, the care taken and control exerted during production and the decisions taken by the method engineers (and patternmakers) at the planning stage. The efforts of the latter will be directed towards producing in the most economic manner, balancing the dressing requirements against the foundry production methods.

(ii) Methods of Dressing Castings

The various processes and procedures associated with the dressing operations are reviewed in detail later in this section.

These may be summarised as:

a) Grinding

- i) pedestal or stand grinders
- ii) swing frame grinders
- iii) rotary hand tools
- iv) automatic grinders
- v) abrasive belt machines

b) Flash Removal

- i) hand held hammer and chisel
- ii) percussion tools

- iii) barrelling

c) Special Operations

- I) machine dressing
- ii) press broaching
- iii) feeder head removal

d) Ancillaries

- I) manipulators
- ii) robots

The dressing shop may also be required to cater for some reclamation by welding and, while it is not required as a dressing operation, many customers require castings to be painted before despatch to obviate rusting.

(iii) Equipment used to Dress Castings

High Frequency Electrical Hand Grinders

Operator opinion of electrical high frequency hand grinders varies considerably. Certain dressing shop operatives prefer pneumatic tools because of their relative 'lightness'. However, other operators tend to favour the high frequency grinders. One of the reasons for this is that electrical grinders are somewhat 'heavier' than their pneumatic counterpart, thus alleviating the necessity to apply too much 'weight' on the tool when grinding.

From the engineering and safety viewpoint, the machines have added advantages over medium voltage hand tools. The electrical system comprises a standard three phase 440 volt 50 Hz supply in 'ring main' form, connecting to rotary frequency converters which, in turn, increase frequency and lower voltage. A typical form is a 125 volt 3 phase 200 Hz system – voltage to neutral, is line voltage divided by the square root of 3, i.e.

$$\frac{125}{\sqrt{3}} = \frac{125}{1.732} = 72 \text{ V}$$

This simple equation illustrates the safety aspect for the operator. If there are only 72 V to neutral, which is earthed, this makes the high frequency hand tool much safer to use than the medium voltage tools.

The majority of down-time is usually due to broken power leads, loose wheel guards, etc. In fact these faults are responsible for roughly 70% of breakdowns which tend to take 15 to 20 minutes each time to repair. In some instances, the operator will not

always report a minor fault, which could be rectified by the electrical department in a matter of minutes. Instead the tool will be continually used until it breaks down completely. This creates various problems, one being the obvious extended down- time caused by metallic particles from the grinding surface entering the air flow ducts in the power tool and embedding themselves in bearing housings, around stator winding and rotors, generally stalling the machine, resulting in overheating and final seizure and burn-out situations.

Some pneumatic hand tools, which are manufactured from an aluminium alloy and which are continually in use on a repetition grey iron casting line, inevitably have the same type of problem. The results are worn bearings, housings, rotors, stator and gearbox failures. The bearing housings, when eroded, have to be replaced, together with bearings, rewind stators, etc. These are by far the lengthiest lasting on average one to one and a half hours per unit. It is recommended that there are always reconditioned machines available from the electrical department 'pool' so production stoppage time is cut to a minimum.

In the average foundry, out of a stock of usable high frequency tools numbering 50, the percentage of units in for repair at any one time is normally around 10%. Coupling this with the amount of castings produced, compared with the cost of spare parts, together with their 'built-in' operator safety characteristics, they are regarded as very efficient. The types of hand grinders used will vary for different applications; for instance, in one well-known foundry, they employ six inch grinders, six inch straight grinders, four inch angle grinders, pencil and die grinders.

Pneumatic Grinders

The secret to success in the use of air grinders is in general that the compressed air should be clean and dry and a lubricator used on each individual grinder. This is essential for efficient operation.

The only problems generally encountered with this type of tool are wearing and sticking of rotor vanes, collet and bearing wear.

Stationary Pedestal Grinders

Very few problems are experienced with this type of machine. When problems do occur, they are generally limited to drive belt wear and the occasional bearing failure. Features of design with the older type machine make it difficult to change drive belts, and indeed the motor, especially with the double ended variety.

In practically all cases, portable dressing equipment is subject to misuse either from overloading or damage occurring from impact. This type of damage can be prevented by providing racks for the tools and a suspension aid should be provided while they are being used.

(iv) Abrasives used in Dressing Castings

The properties required of any substance to be used as an abrasive are:

- a) the hardness must be above nine on the Moh's Scale (diamonds are ten);
- b) it must be available as sharp particles in mesh sizes from 10 ASTM upwards either as natural crystals or produced by crushing and sifting from the massive form;
- c) chemically and physically it must not inherently present a health hazard when in use;
- d) the particles must be able to be bonded in a desired shape or to a rigid or flexible substrate;
- e) the substance must be available:
 - in controlled quality
 - in quantity
 - at a price commensurate with its acceptability for the above purpose.

Historically, the natural minerals, such as native grit stone, Suffolk flint, emery from Naxos, garnet from Africa or America and corundum from India were deficient on one or more of the foregoing requirements and with the predominance of dry grinding elimination of the free silica content became a pre-requisite.

Modern abrasives are based on the discovery and production of artificial corundum (fused alumina) by the French and of silicon carbide by Acheson in America, both in the 1900s. Artificial corundum is made by fusing purified calcined bauxite Al_2O_3 in a high current consumption vertical electric arc furnace at 2000°C , whilst gradually adding the feed and withdrawing the electrode over a period of six hours to attain a melt of about 1.5 tonnes. This melt is allowed to cool slowly in situ to produce a white crystalline mass of hardness 9.5 (Moh's Scale), somewhat resembling white lump sugar in appearance. Subsequent crushing, sifting and magnetising results in particles or grits to pre-determined mesh sizes, but hardness alone is not enough. This pure white product tends to fracture down the cleavage plane of the crystal, giving an admirably sharp, but rather brittle, particle most suited to the fine finishing of hardened steel and hard alloys. Introduction of controlled amounts of trace elements chemically combined with the alumina melt modifies its crystal structure and consequent fracture to give controlled particle shape and toughness which vastly affects grinding performance. Such trace

elements impart a characteristic ruby, pink, pale emerald green or reddish brown colour to each variation whilst the toughness of the brown variety can be further enhanced by heat treatment. This latter is much preferred for grinding steel, light alloys or ductile metals in the cast, forged or fabricated condition.

c) Automation of the Fettling Process

Many foundries use a batch method for processing castings through the cut-off and grinding operations. This method increases the handling of the castings and, therefore, labour costs.

Increase in productivity may be accomplished by repeated delivery of a casting at a uniform rate and in a similar position, which requires minimum reach by the operator. The more consistent location of the casting for each cycle in the work-station reduces the time taken to locate the casting, so reducing operator fatigue.

The automatic transfer of the casting to the grinding or cut-off work-station may make use of a belt or vibrating conveyors, overhead monorail or other methods. When holding larger castings, a clamping fixture using a hydraulic positioner may be needed to grip and move the casting through the grinding operations.

Robots can also be used to move castings through the grinding operations. When two or more different size and/or shapes of grinding wheels are required to grind a casting, grinders may be arranged in a cell with a robot or manipulator moving the casting from grinder to grinder. The cell application may also be applied to runner and riser removal prior to grinder requirements.

When using robots and/or manipulators to move castings through a work cell, production volume rates and casting size and weight should be compared with the weight capabilities and speed of the robot.

Other robot applications may be designed to locate the casting in a clamped fixture. The robot can then be programmed to bring the required variety of grinding wheels to the casting.

Cut-off and grinding operations should be arranged as early as possible in the sequence of operations in the casting cleaning process. Since cut-off operations will remove runners and risers and grinding will remove parting lines and core fins, the castings will be easier and safer to handle in subsequent operations.

For high volumes of similar components, automatic flash removal can be included in the process flow. This can be achieved by an automatic cropping machine, similar to a press in operation, where the casting is placed in a form and the excess flash cropped off.

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Variations between different moulding patterns should be taken into consideration. Larger castings of the same shape can be automatically pushed through a de-finishing fixture situated in the process flow line.

With round components, such as brake discs, automatic grinding machines to remove casting ingates can achieve high levels of output.

Best practice is for foundries, if possible, to perform a machining operation on the castings prior to shipping. This adds value to the product and reduces the labour-intensive fettling operation, as some fettling can be replaced by first-cut machining operations.

(I) Automatic Grinding

In automatic grinding with the correct choice of modern grinding methods, four to five times the rate of metal removal is achieved in comparison to manual grinding methods.

The output factor 'Q' for manual grinding, using modern grinding methods, lies between 8 to 20 but with automatic grinding, between 30 to 100. The appreciably greater life of the grinding discs brings savings in the cost of grinding materials and involves less time for changing grinding discs. The reasons for longer wheel life are to be found in the removal of the dressing processes, and there is the choice of harder bonded grinding wheels.

Modern grinding materials such as zircon and corundum reach their full effectiveness only with high contact pressures, a notable advantage in the case of automatic grinding.

The positions of the ingates and flashline are of decisive importance for the use of automatic rough grinding machines. If the gate and flash are on the same level, the casting is well suited for automatic grinding. If the geometric shape of the workpiece is in the shape of a disc, or is flat, this gives optimum conditions for automatic grinding. Irregularly shaped pieces such as crankshafts, connecting rods and the like, can be automatically ground with great economy.

It is common to use automatic grinding equipment for the processing of cylinder blocks and heads, when considering high volume items.

d) Weld Repair

This is allowed on many steel, and some iron castings, especially the larger ones. Welding can take place at different positions within the flow process depending on the type of iron or steel casting that is being repaired. On the weld repair station pre-heat facilities should be available.

The welding process used and the filler material is again dependent on the type of steel castings. Reference should be made to national and international welding standards

8.2 Cleaning Of Castings

a) Introduction

This part deals with the cleaning of iron and steel castings. It contains a review of cleaning processes, but the major part of the work is devoted to shot blasting techniques.

This part is intended to assist a foundry when selecting a suitable shot blasting machine. Among the factors considered are the matching of machine with the casting to be processed and the selection of the correct abrasive to produce the desired surface finish. Information on legislation relating to shot blasting is given. Other important areas considered are machine maintenance, running costs and reducing the need for shot blasting.

b) Reasons for Cleaning Castings

When a casting leaves a sand mould it may have adhering to it quantities of loose and burned-on sand, together with denseners, sprigs and surplus metal in the form of flash and running system. Quite a lot of this extraneous material is removed by the shake-out machine, but further cleaning is required before the casting is safe to handle or commercially acceptable.

In a grey or malleable iron foundry the running system may break off during shake-out, but this is unlikely to be the case with SG or steel castings. Flash around core prints and joint line may cause core sand to be retained in the casting and there will be a skin of sand and carbonaceous deposit adhering to the metal surface.

Flash is readily removed by hand, or in more sophisticated plants, by robot or trimming machine. This allows entrapped sand to be removed mechanically but the skin of adhered sand is a more difficult problem. This skin must be removed before the casting can be accepted for machining or further processing.

When components are heat treated after casting, oxide scale may be formed on the surface. This scale has to be removed, and, where this proves impossible by conventional means, chemical methods may have to be used.

c) *Methods of Cleaning Castings*

The methods available for cleaning castings are many and varied, selection depending on cost and application. In some non-ferrous applications shot blasting is too severe and alternative methods are required. A list of the principal cleaning methods follows:

Wire Brush

A tedious method of cleaning, nowadays generally reserved for sample inspection of castings immediately after cooling.

Water Blast (Hydro-blast)

Cleaning using a high pressure water jet has the advantage of being able to reclaim the sand.

Chemical Methods

- Pickling baths, both acidic and alkaline, mainly used for the removal of scale or burned-on sand.
- Leaching of precision castings by washing in an alkaline solution, possibly with the addition of glass beads or steel grit.

Tumbler Barrel (Rumblers)

Used mainly where a polished finish is required, for example, prior to plating and particularly useful for small castings that are not suitable for shot blasting.

Vibratory Cleaning

Used for cleaning and deburring of both ferrous and non-ferrous castings. Castings are vibrated through a machine in contact with specially designed abrasive media. Widely used in the die-casting industry.

Ultrasonic Cleaning

Mainly used as an alternative to trichlorethylene vapour degreasing of aluminium die castings.

Power Brushes

For polishing castings prior to plating. Air blast cleaning. Uses a range of abrasive media, both metallic and non-metallic, directed at the casting in a stream of air.

Shot Blasting

The most common method employed for cleaning castings, to which the rest of this section is devoted.

d) Reasons for Shot Blasting

- i) To comply with legislation which prohibits the grinding of castings which have sand adhering to them.
- ii) To prevent excessive tool wear during machining which would occur if the casting surface is not adequately cleaned.
- iii) To give the casting a visually acceptable surface finish.
- iv) To expose the casting for inspection.
- v) Where the metal has little ductility, to assist in the removal of flash and running systems using a barrel machine.
- vi) To debur castings following certain grinding or fettling operations.
- vii) To clean the casting after other processes (eg crack detection, heat treatment).
- viii) To assist in de-coring.
- ix) As an aid to sand reclamation.
- x) Surface preparation for subsequent finishing operations (eg galvanising).
- xi) Surface peening to improve mechanical properties.

e) Types of Shot Blasting Equipment

Blasting has been defined as:

the cleaning, smoothing, roughening or removing of part of the surface of any article by the use of an abrasive, of a jet of sand, metal shot or grit, or other material, propelled by a blast of air or steam or by a wheel.

Within the foundry industry shot blasting has taken precedence above all other processes as a method for cleaning castings. A wide variety of machinery is available for this purpose, but all involve placing the castings in a sealed chamber and directing a stream of abrasive at them. The abrasive is propelled in a stream of compressed air or thrown from revolving wheels, the latter being the more popular method.

There are five basic elements in any shot blast equipment:

- i) The means to impel abrasive at the work piece:
 - a centrifugal wheel
 - compressed air nozzle
- ii) The means for containing the abrasive in one zone:
 - a cabinet or room

- iii) The means for presenting work to the abrasive stream:
 - work handling system
 - tumbling work
 - rotating tables
 - hook carriers
 - overhead conveyors
 - roller conveyors
 - conveyor belts
- iv) Abrasive cleaning and recycling system:
 - hoppers
 - scrolls
 - elevators
 - pipes
 - critical for foundries – air wash separator
- v) Dust extraction system:
 - dust collectors
 - ducting

Each element is important because the impact operation relies on all elements functioning correctly and efficiently.

General purpose machines may be divided into four broad categories:

- shot blast rooms (including hand cabinets)
- table machines
- tumblers
- hook and monorail machines.

In addition, special machines are continually being designed to accommodate a particular type of casting, for example, camshafts or ingot moulds.

Shot blast rooms and cabinets have the advantage of flexibility and effective cleaning through the close control of the hand-held hose. They may be operated from outside through protective sleeves or require the operator to wear a special suit and enter the blast room with the castings. In general they cater for the two extremes of castings size, cabinets being used for delicate work and shot blast rooms where there is a low output of large, complex castings.

Each of the other categories encompass several different designs of machine and the final choice is governed by the type, size and output of castings. Exhibits CG to CI

illustrate the variety of machines available and can be used as a general guide for machine selection.

f) Abrasives Available for Shot Blasting

The range of different metallic abrasive types available on the market would be expected to satisfy any conceivable application. Within each area of application there is a wide range of abrasive costs, cleaning cycle times and maintenance factors to consider. The correct choice of abrasive type will have considerable influence on whether the objectives of the process are met at the optimum cost. Before elaborating on the various criteria governing abrasive selection, it is important to state the fundamental objectives of the process in order of priority:

- *Surface Finish* – this will depend on the market for the casting. Whilst a clean casting, free from sand and scale may be adequate for most customers, subsequent surface treatments (eg enamelling) may demand special shot blasting considerations.
- *Cleaning Speed* – once surface requirements have been defined, correct choice of process variables ensure optimum overall costs. Long blasting times waste abrasive and increase maintenance, whereas too short a cycle frequently gives rise to reblasting which, in addition to extra costs, causes interruptions in production.
- *Cost of Materials and Maintenance* – the abrasive action which cleans the casting also wears out the machine and destroys the abrasive itself. Hard abrasives clean faster, produce higher rates of machine wear and have shorter lives than soft materials. It is tempting to use the choice of abrasive as a control on maintenance costs to the detriment of the first two objectives stated above and vice-versa.

Clearly the implications of the three objectives are closely related and no one variable should have overall control. The inevitable compromise is based on abrasive type, performance and cost and is very dependent on the type of plant and its operation.

(i) Abrasive Form

Metallic abrasives appear in two major forms, shot and grit. Shot consists of small round spheres that are produced by the disintegration of molten metal by water, whereas grit is manufactured by crushing large shot sizes and irregular shapes into angular pellets. Cut wire is also used.

(ii) Abrasive Type

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Physical characteristics of the abrasive largely control the performance of the blasting process. Important properties of the abrasive are:

- hardness
- breakdown rate
- size distribution during operation.

These considerations are obviously inter-related and will depend on the material from which the shot is manufactured. Blasting was first carried out using chilled and malleable iron shot and grit, but the advent of steel abrasives has reduced their use to particular circumstances, eg where heavy loss of shot by 'carry out' occurs.

The general characteristics of the main types of abrasive are outlined below, typical specifications being listed in Exhibit CJ.

Chilled Iron

Produced as white cast iron middle to high phosphorus content. The hardest of all the commercially produced abrasives, the sharp, angular pellets provide a fast cleaning and cutting action at low initial cost. Unfortunately, its hardness also leads to rapid breakdown of the shot and heavy wear on impeller type machines. Its use is therefore becoming confined to compressed air plant or to special applications where the casting requires an etched finish for special surface coatings.

Malleable Iron

Malleable iron shot is generally more expensive than chilled iron abrasives. However, this softer material can have double the useful life of chilled iron and leads to reduced wear on plant. Best used on castings which are relatively easy to clean and where abrasive loss is unavoidable. Can be used to good effect where castings can be hung or tumbled.

Cut Wire Pellets

Best used for very tenacious contamination in airless machines, the coarser grades producing a rough surface finish. Retains its initial size longer than other premium abrasives which can be both an advantage and a disadvantage. Impeller wear is similar to that of steel shot once the sharp edges of the cut wire have been removed. Hence it is recommended that cut wire be added to the machine in small regular quantities.

Steel Abrasive

This material is substantially more expensive than iron shot-grit but has a considerably longer life (4 to 8 times). This allows the user to maintain balanced pellet size operating conditions (which are essential for efficient cleaning) more easily. Consequently, it is most economical where abrasive loss is minimal.

It is best used where resistance to initial breakdown is important. In the higher hardness ranges cleaning performance improves but consumption increases. It produces a smooth texture surface, dull grey in colour.

(iii) General

Each type of abrasive shape has its own advantages and disadvantages. In modern airless equipment steel shot will remove most contaminants, but when occasional

problems are experienced with burned-on sand or scale conditions, a higher hardness steel grit is usually found the most suitable.

Choice of abrasive is, of course, the most important aspect of the process. It is the only part that comes into direct contact with the workplace to achieve the desired result, whether removing sand, scale, rust or preparing the surface for a subsequent process like powder coating, enamelling, metal spraying, etc. The type, size, shape and hardness of the abrasive pellet is critical for the type of required finish.

(iv) Abrasive Size

The size of the shot or grit will affect both the surface finish and the cleaning cycle. To obtain optimum cleaning conditions, a 'balanced' mixture of particle sizes is required in the machine. As a general rule, this optimum will be obtained with the smallest particle size which will remove the heaviest contaminants. The finer the abrasive, the more impacts per kilogram of shot thrown by the impeller wheel, leading to greater coverage of the work surface and hence optimum cleaning conditions.

Exhibit CK is intended as a guide to the grades of chilled iron and steel abrasives in general use.

(v) Abrasive Quality

Inferior abrasives will affect the machine performance and increase the cost of the operation. The abrasive used should therefore:

- Meet the requirements of the grading specification.
- Contain the minimum of irregular shapes. These pellets do not provide the impact of solid shot or chunky grit.
- Be free from excess voids or hollows.
- Have a minimum shot density of 7000 kg/m³.
- Have the desired microstructure (important for maximum toughness and long life).
- Meet the specification average for hardness. It is particularly important that individual hardness readings are within the specified range. A wide range of hardness results will affect both the cleaning power and life of the material, despite possibly giving the required average hardness.

8.3 Heat Treatment

The majority of steel castings, and some iron castings, are heat treated prior to dispatch to confer specific properties relating to the specification and/or to stress relieve the castings.

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The heat treatment process is often specified by the customer on the casting order. Some foundries do not have their own heat treatment or insufficient capacity and sub-contract this process.

Heat treatment must follow the specified heating times, solution temperatures and cooling rates to obtain the desired properties. Castings size and section thickness also dictate their processing route. Some heat treatments involve air, oil or water quenching, whereas others specify furnace cooling.

As applied to iron and steel castings, the term heat treatment means any thermal treatment or combination of thermal treatments involving the heating and cooling of castings. Heat treatment may be applied to relieve internal stress, homogenise the cast structure, refine the grain size or alter dispersion of phases in order to obtain some desired property or combination of properties. These may be mechanical properties such as yield strength, tensile strength, percentage elongation, impact energy, fracture toughness (at normal and sub-zero temperatures), hardness or fatigue strength; or physical properties such as magnetic permeability or resistance to wear. Heat treatment may also be applied for some intermediate purpose, such as to improve machinability, even though a further heat treatment has to be given after processing to obtain the optimum final properties.

Generally, the term heat treatment infers that the whole casting is heated. For other treatments, such as local stress relief, differential hardening or flame hardening, the term thermal treatment is often used, although this is by no means standard terminology. In some countries, the term heat treatment usually implies full hardening followed by tempering.

With reference to Exhibit CL the principal operations in heat treatment as applied to iron and steel foundry practice are as follows:

Austenitising

The process of heating a steel to above its A_{13} temperature to produce a wholly austenitic structure.

Homogenising

A high temperature treatment for castings applied with the intention of removing dendritic segregation. Temperatures in excess of 1000°C may be used.

Annealing

Full annealing of steel castings is carried out by heating the casting to a temperature above the A_{13} , and after holding for a period of time, cooling in the furnace to a level approaching room temperature. In practice, castings are withdrawn when the furnace temperature has reached approximately 300°C.

Sub-critical annealing involves heating to a temperature below the A_{13} and cooling slowly in the furnace. It is used for stress-relief after normalising or welding, or other operations which may cause stresses to be set up, or for softening high-alloy steel castings.

Normalising

A treatment similar to full annealing except that castings are removed from the furnace and allowed to cool in still air.

Quenching

Castings are heated to an austenitic temperature, usually somewhat lower than that employed for annealing, and held until the temperature is uniform throughout, and then rapidly cooled. The desired cooling rate is usually obtained by immersion in a liquid, although an air blast may be used.

Tempering

Tempering involves heating castings to a temperature below the A_{13} , and in hardened steels is carried out to effect the recovery of ductility and toughness that is brought about by the precipitation and coalescence of carbides. Steels that have not been fully hardened are often tempered, but this is more correctly referred to as a sub-critical stress-relief anneal. In American literature the term 'draw' is sometimes used and is synonymous with tempering.

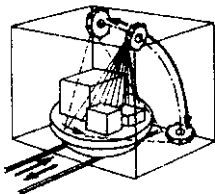
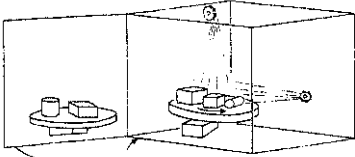
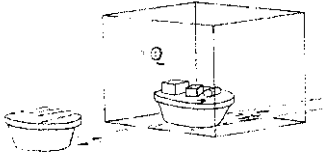
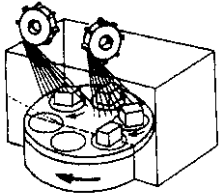
Details of heat treatment usually applied to steel castings:

- i) Plain carbon steels are usually annealed, or normalised, or annealed and normalised.
- ii) Low and medium alloy steels are usually annealed, hardened and tempered, the hardening being an air cool or an oil or water quench, depending on the alloy content (hardenability) and section thickness of the castings.
- iii) Hadfield 13% Mn steel is toughened by quenching in water from 1050°C. Any subsequent heating tends to cause brittleness.

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- iv) Austenitic Cr-Ni steels are usually solution treated, by heating to 1050°C to 1150°C and rapidly cooling. For thin sections, cooling in air is adequate. The highly alloyed heat-resisting steels are usually put into service without being heat treated, but a stress-relief treatment is sometimes applied.
- v) Variations to the above heat treatments occur in order to meet special circumstances or requirements.

Exhibit CG Table machines

Type of Machine	Sketch	Size and type of casting	Features	Notes
Plain table		Mixed loads, usually medium to large castings	1 to 3 impellers (11-30 kW)	Table rotates. Suitable for fragile castings
Swing door table		Mixed loads, usually medium to large castings	1 to 2 impellers (15-30 kW)	Can be of single or double door type
Twin-table shuttle type		Medium to small parts	1 impeller (11 kW)	
Multi-satellite table		Flat castings	1 to 2 impellers (15 kW)	

NB A feature of all table machines is that castings must be physically turned over to expose the surfaces to be shot blasted.

Exhibit CH Tumble machines

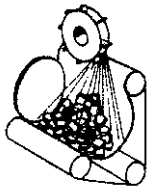
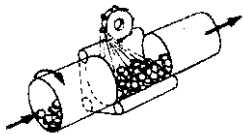
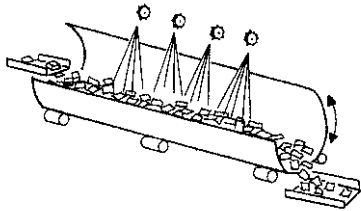
Type of Machine	Sketch	Size and type of casting	Features	Notes
Batch barrel		Very wide range of casting weights, but castings must be robust.	1 to 2 impellers (4-56 kW)	Thorough cleaning of all faces
Continuous barrels		As for batch.	1 to 2 impellers (18.7 kW)	
Continuous oscillating barrel		Mixed loads, small to medium castings	Up to 8 impellers (22.4 kW)	Very high output

Exhibit CI Continuous machines

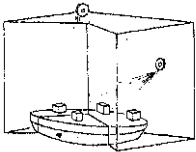

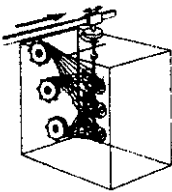
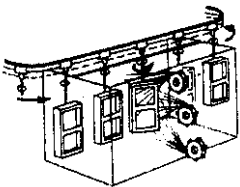
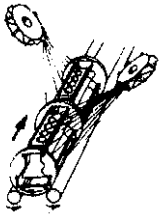
Type of Machine	Sketch	Size and type of casting	Features	Notes
Continuous table		Small to medium	1 to 3 impellers	Operator loads, turns and unloads castings on the exposed segment of the table.
Continuous belt		Small to medium	1 to 3 impellers	Rubber belt with downthrowing wheels.
Hook		Very useful for medium to large complex castings	Multi-wheels 1 to 4 impellers (11–22.4 kW)	Casting powered into and out of cabinet on hook.
Monorail		Medium to large	Multi-wheels (15–30 kW)	High production rates. Can be used as knock-out machine.
Ram cage/tunnel		Medium – cage is designed to suit the casting	Multi-wheel	Special purpose machine very high output. Castings or cages rammed against one in front as they pass through shotblast tunnel.

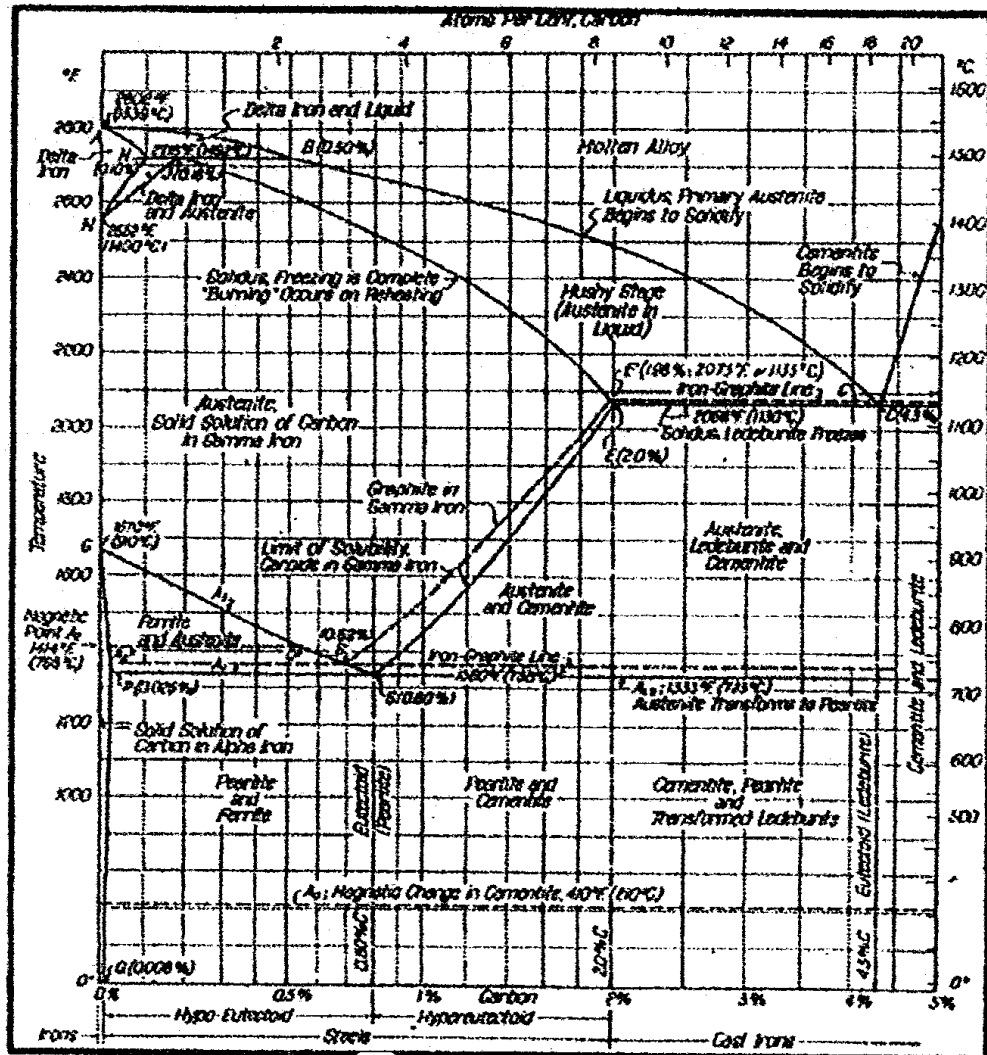
Exhibit CJ Characteristics of principal types of abrasive

Abrasive Type	Typical Hardness	Guide Specification					Microstructure
		2.80–3.20 % C	1.00–2.00 % Si	0.50–1.50 % S	0.20–1.00 % P	0.50–1.00 % Mn	
Chilled Iron	56–64 RC						Network of carbides in a matrix of martensite.
Malleable Iron	30–40 RC	As for Chilled Iron					Nodules of tempered carbon in a matrix of pearlite.
Cut Wire Pellets		Cut from wire with a tensile strength of 161–180 kg/mm ²					
Steel	40–50 RC	0.85–1.20 % C	0.40 min % Si	0.05 max % S	0.05 max % P	0.60–1.20 % Mn	Uniformly tempered martensite with fine, well distributed carbides.

Exhibit CK Typical grades of steel and chilled iron abrasives used for cleaning various castings

Castings	Shot (round) BSI/SAE	Grit (angular)		Nominal Size (mm)
		BSI	SAE	
Grey iron				
Large	S550-S460	G55-G47	G14-G16	1.40/1.20
Medium	S460-S390-S330	G47-G39-G34	G16-G18-G25	1.20/1.00/0.85
Small	S330-S230	G24	G25	0.85/0.60
Malleable				
Large	S550-S460	G55-G47	G14-G16	1.40/1.20
Medium	S390-S330	G39-G34	G18-G25	1.00/0.85
Small	S330-S230	G34(G24)-G17	G25-G40	0.85/0.60/0.42
Steel				
Large	S780-S660	G66-G55	G12-G14	2.00/1.70/1.40
Medium	S550-S460-S390	G47-G39	G16-G18	1.40/1.20/1.00
Small	S330-S280	G39-G34	G18-G25	1.00/0.85
Non-ferrous				
Large	S230-S170	G17-G11	G40-G50	0.60/0.42/0.30
Medium	S110	G11-G07	G50-G80	0.13/0.18
Small	S70	G07	G80	0.18

Exhibit CL Iron-carbon equilibrium diagram



9.0 PATTERNMAKING

9.1 Introduction

As the wind of change blows throughout our industry, probably one of the areas it blows the hardest is in the sector of patternmaking. The technological changes which are now being imposed upon the castings industry to produce more complex and intricate castings, are having a greater effect upon the way patternmakers have to think and the way in which they are obliged to operate. The way in which patterns are designed and constructed forms the foundation of all production processes employed within the castings industry, irrespective of whether or not they are designed for the mass production of castings or for the jobbing sector of the industry.

An understanding of what is required by the foundry is an essential skill which the patternmaker has to develop. This necessary skill is one of the prime requirements of today's engineering industry, since the complexity and intricacy of modern designs place greater demands upon the combined knowledge of both the castings engineer and his/her partner, the patternmaker.

With these greater demands being placed upon the people who operate within the industry, it is regrettable that the education and training facilities available for patternmakers have recently undergone a serious contraction. Many traditional centres for education have withdrawn their courses, leaving only a very small number of colleges who offer recognised courses. The whole system of educating and training patternmakers is now under serious review and hopefully this problem will be resolved within the very near future.

The object of this chapter is to outline the various technologies and skills which are available to the patternmaker and to outline how they may be best employed to the advantage of both sectors of the industry. A modern industry which operates within a globalised market will only succeed if it has the necessary level of skills both on the shop floor and in the management structure to respond to the demands of the emerging market place.

9.2 Pattern Construction

A patternmaker operating in today's environment has to develop an all round knowledge of the industry linked together with an understanding of the part that a casting produced from a pattern plays in the operation of an engineering component. The personal development of this knowledge is a vital component in any patternmaker's development because it is this knowledge which will determine the way in which the patternmaker will commence the design and construction of the pattern. The escalation of specialisation which is being developed within the manufacturing industry now demands that the patternmaker has to develop a much greater degree of understanding of the processes involved. Running in parallel with this is still the requirement for the trainee patternmaker to develop those basic skills which are vital for him/her to perform the underlying operations involved with the production and construction of a pattern.

An engineering drawing is made to describe the object clearly and accurately without the use of ambiguous words. It is a means of conveying an idea from one person to another.

A drawing is a form of shorthand made up of lines and symbols rather than words and must be capable of being understood by anyone who has the knowledge and ability to read an engineering drawing.

Standards are laid down for most engineering practices to enable everyone to produce to the same quality and accuracy. The British Standard 308 for engineering drawing practice provides the basis for all drawings produced in the UK. The international equivalent is based on the metric unit and is called the International Systems Organisation (ISO). The draughtsman's dilemma is to represent a three dimensional object onto the two dimensional surface of a drawing. Clarity is essential in a drawing since it must define the shape of an article by its outlines and its size using dimensions and the transfer of working information in the form of note. It must enable a craftsman to produce the article exactly as the designer wants. There are two methods that can be used to achieve this objective.

a) Pictorial Drawing

Pictorial drawing gives an overall impression of the appearance of the article. Such drawings are used mainly for explanatory purposes but seldom as working drawings. Since the complexity of most engineering parts requires the conveyance of more information than can be provided on a three dimensional view. There may be as many as six faces on an object that have features to be drawn and dimensioned.

b) Orthographic Projections

Orthographic projections taken from the Greek word meaning 'right angled drawing'. An engineering drawing will be composed of a number of separate elevations, each representing the object viewed from different positions. These views are arranged relative to one another in a standard format.

The system of projecting these views on a drawing should be indicated by the appropriate symbol otherwise the direction in which the views are taken should be clearly indicated by an arrow. If neither of these methods has been used then the patternmaker will need to apply both angles of projection to see which fits.

1st angle projection is known as European.

3rd angle projection is known as American.

Both are approved internationally and are regarded as being of equal status.

c) Finding a Joint Line

A joint line on a pattern is necessary to allow for the separation of the two halves of the mould and to allow the pattern to be withdrawn from the sand.

To establish this joint line it is necessary to study the drawing of the part and determine the widest points on each face by first looking at the plan view and then referring to the other elevations to confirm first thoughts. By linking these points together, a joint line can be determined. This line will be the best available, avoiding all overhangs, projections or indentations on any of the pattern faces.

d) Pattern Taper

Taper is the angle or slope on the vertical sides of a pattern to allow it to be lifted from the mould without damaging the surface of the sand.

The direction of the taper is governed by the position of the joint line. The pattern is always larger at this line.

There is no absolute rule as to what degree of taper should be used on any particular pattern. There are many features to be taken into consideration, eg

- depth of pattern
- method of mould production

- material from which pattern is made
- design features of the part.

It is sometimes necessary to vary the angle of taper from the top half of the pattern to the bottom, or even in different places on the same half.

Typical Tapers:

Cast faces 1–2°

Print faces 5–10°

The direction of the taper is governed by the position of the mould joint. The pattern is always larger at the mould joint.

Exhibit CM shows the angle or slope on the vertical sides of patterns and coreboxes, which is provided by the patternmaker to assist the clean and easy withdrawal of the pattern from the moulding material.

e) Contraction Allowance

When molten metal has been poured into a mould it begins to cool down to room temperature and solidify. This process can vary in time from several hours to several days according to the type of metal and the size of the casting. As the metal cools, it shrinks and the solid casting becomes smaller than the mould. The patternmaker must take this shrinkage into account when making a pattern by adding a shrinkage or contraction allowance to all the dimensions. The pattern is, therefore, made larger than the resultant casting.

Special contraction rules are made for this purpose, but there are times when rule measurement is not accurate enough, then the contraction allowance has to be added by calculation.

All metals and alloys of metals, contract by different amounts, so a range of contraction allowances is required, eg

- Cast iron will contract 1%
- Cast aluminium will contract 0.7%
- Alloy steel will contract 0.5%.

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It is by no means unusual for more than one contraction allowance to be used on the same casting. Reasons for this will be dealt with later.

Information regarding the type of metal to be used and its contraction must come from the foundryman and must be known by the patternmaker before any work can be done.

f) Machining Allowance

Most castings will require some form of machining operation to be carried out by an engineer. A face on a casting, to which another part is to be fixed, will require machining in order to ensure its flatness, smoothness, dimensional and surface accuracy.

To enable the engineer to carry out these operations the patternmaker must provide additional metal on those surfaces indicated on the drawing as machined faces.

The drawing symbol for a machined face is shown thus and may be accompanied by a number indicating surface finish tolerance. There is no hard and fast rule about the amount of allowance to be made. Normally 2.5–3.0 mm is used but very small castings may have as little as 1 mm, whereas large machine beds may require 10–12 mm. Variations in the amount of machine allowance depends upon a number of factors.

g) Set Out

The patternmaker will be given a drawing of a part to be cast in metal. The drawing may be full size, a reduced size, or only a free hand sketch. A professional drawing will have all the information required concerning the part, the metal in which it is to be cast, the machining required and the final treatment of the casting. Read the drawing carefully.

In addition to the drawing information, the patternmaker will need to find out other relevant facts:

- how many castings will be required?
- what moulding/coremaking methods are to be used?
- allowances, eg contraction, machining, etc

9.3 Pattern and Corebox Finishing

When the manufacture of a pattern and corebox has been completed, the wood surfaces that will come into contact with the foundry sand must be coated with a protective medium such as paint or varnish. However, the surface of the wood must be properly prepared

before any coating is applied. In the case of patterns and coreboxes this means that all surfaces should be smooth, free from all tooling marks and any surface blemishes such as cracks, holes, loose knots or tears in the grain. Any fault or blemish that cannot be removed should be filled with a suitable proprietary brand of wood filler.

It is essential that the type of paint or varnish to be used is compatible with the binding agent in the sand used by the moulder/coremaker. The foundry should be consulted before applying a coating to pattern equipment. Most of the coatings are applied by brush, although some sealers and varnishes are available in aerosol spray cans. The first coat will soak into the surface of the wood. After a few hours of drying time at room temperature, all the surfaces should be smoothed down with a fine grade sandpaper and a second coat added. It will then be a matter of judgement as to whether a third coat will be necessary.

In the interest of health and safety, the complete process must be carried out in a well ventilated room or one fitted with fume extraction.

It is important that all the rules governing personal protective clothing and personal hygiene are observed. After sanding down the pattern equipment in between coats of paint or varnish, the dust should be removed with a cloth and never blown by mouth or by any mechanical blower.

a) *Reasons for Applying Surface Coating to Pattern Equipment*

- i) To prevent the moisture or chemicals in the foundry sand from penetrating the surface of the wood. Such penetration may cause the wood to distort, grain to lift, glue joints to open. All or any of the defects will affect the quality and accuracy of the pattern equipment. The equipment may also be put into storage for many years, being used only occasionally.
- ii) To improve and protect the surface finish by preventing sand adhering to the surfaces of the equipment after it has been rammed in the mould. A good surface finish ensures a clean lift from the mould and a smooth working surface in the mould.
- iii) To colour code the patterns and coreboxes. Foundries may vary a little in the colour schemes they use but one in common use is:

Red	–	casting surfaces
Black	–	pattern prints
Yellow	–	machined faces
Green	–	loose piece seatings

- iv) After constant use certain areas of the pattern equipment can be seen to have worn where the abrasive sand has worn through the coating to reveal the wood underneath. This is an early indicator of an area in need of repair or simply another coat of paint to maintain the smooth surface and accuracy of the equipment.

9.4 Materials used in Patternmaking

a) *Reasons for the Variety of Materials*

A patternmaker must be prepared to work with a variety of materials and will need to develop the necessary expertise to form and shape them.

The materials in general use fall into three main groups:

- wood and composites
- resin and polyurethanes
- metals

When a pattern is required a choice of material has to be made based upon a number of known facts. Each material has its advantages and disadvantages over the other and the selection of materials suitable for the job becomes an important part of the patternmaker's decision process.

Pattern equipment is made to serve a specific purpose and must, therefore, meet certain specific criteria. Some of the facts to be considered are as follows:

- How many castings are required?
- How often will the pattern equipment be used?
- Will the pattern equipment be stored for only occasional use?
- What tolerance is required?
- What durability is required?
- What will be the size of the pattern and construction method required?
- Will the pattern and corebox need to be made in the same material?
- Will the pattern equipment be used manually in the foundry?
- What type of moulding machine or coreblower will be used?
- Is the mould/corebox to be stripped by hand or by ejection?
- What time limit is there for manufacture?
- What are the restraints of cost?

b) *Wood used in Patternmaking*

There are two main categories of timber:

- softwood
- hardwood

Softwoods are from coniferous or cone bearing trees with needlepoint leaves. Hardwood are from broadleaf trees which stand bare during the winter months.

These two terms are chiefly of botanical significance. Hard in relation to wood does not imply strength or weight and soft does not suggest unreliability or lightness.

From a wide range of timbers available the patternmaker selects just a few that are suitable. The timber selected must have the following characteristics:

- easy to work by hand
- straight grain
- relatively free from knots and shakes
- low moisture content (10–15%)
- strong and not liable to warping
- quality sawn

Popular types of timber used are:

<u>Hardwood</u>	Mahogany (Brazilian or Honduras)
	Jelutong

<u>Softwood</u>	Canadian Yellow Pine
	Western White Pine

c) Composite Materials

Plywood is a man made board manufactured to precise engineering requirements with predictable and reliable mechanical properties. It is made by gluing together thin sheets of wood, approximately 1 mm thick, under pressure. The grain on each sheet is set at 90° to the other. This method of production has the advantage of producing material that does not shrink and has greater strength than the equivalent thickness of solid timber.

Sheets of plywood are sold in two popular sizes:

1524 mm x 1524 mm

2440 mm x 1220 mm

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Thicknesses vary from 3 mm to 24 mm. A patternmaker usually requires good quality Finnish or Swedish birch faced plywood because of its smooth finish and close grain. A sheet of plywood is usually faced with birch and is made up between these with layers of softwood. Top quality plywood will be hardwood throughout.

Blockboard is another example of wood board material for which patternmakers can find a use. The surface ply is birch but the inner core consists of wood strips not exceeding 25 mm wide. The sheet sizes can be the same as plywood but the thicknesses are very limited.

Medium density fibre board (MDF) – this is supplied in sheets of similar dimensions to plywood and is used by many patternmakers as a useful substitute. It keeps flat, has a smooth surface, has no grain and can be used in constructional work in patterns and coreboxes.

Polystyrene blocks – each material mentioned has a particular use for the patternmaker. A polystyrene pattern, unlike another, can only be used once, because it is burnt away in the mould. It is purchased in blocks of large sizes yet it is easily cut with a bandsaw thin blade, of a very sharp knife. Pieces and shapes are cut from block material, fixed together with a contact adhesive and masking tape over the joints.

The material is soft and lightweight but must be handled with care because the finished product can easily be damaged before reaching the foundry.

Model board – the collective name for this particular type of product is ‘cured polyurethane board’. The ‘board’ is a machinable slab of high quality polyurethane.

There are two methods used in its manufacture. One is a filled resin system cast into block form under vacuum. The other is a filled foam system cast under pressure. The boards are produced in a selection of thicknesses: 20 mm, 30 mm, 50 mm, 70 mm, 100 mm.

d) Resins and Polyurethanes

These are materials that are not cut and shaped by hand tools but are mixed together and poured into a mould.

Epoxy resin is such a material which is a mixture of two or more liquids, which react with each other to form a solid. The basic ingredients of an epoxy resin are:

liquid resin + solid filler + liquid hardener + liquid accelerator

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By mixing different combinations of these materials one can achieve a filled gelcoat, a laminating mix, a pouring mix and, by adding a large amount of filler, a hand mouldable paste.

This is then an extremely useful and flexible system for all sizes of resin products.

However, despite its many advantages there are disadvantages:

- Weighing and mixing is time consuming and messy and may lack consistency of result.
- Curing time is 24–36 hours at room temperature and must not be short cut if quality and dimensional accuracy are to be maintained.
- Considerable experience and expertise is needed to achieve the required results.

To overcome some of these problems, manufacturers have developed two part mixes, where a hardener and a filled resin are supplied in separate tins in the correct mixing. All that is required of the patternmaker is to pour the contents of one tin into the other and mix thoroughly.

Resin patterns may be cast solid, or be strengthened by the inclusion of glass fibre strands or matting. Large resin patterns may be constructed using a framework of square box section fibre glass tubes, giving strength, eliminating shrinkage and remaining relatively lightweight.

A range of fillers give different surface finishes, textures and wear life, eg aluminium, slate powder, carbide. Each brand of resin will serve a particular purpose and their selection is very often a matter of personal choice. All resin ingredients are supplied with mixing instructions, curing times and demould times, together with a health and safety fact sheet. There are many hazards to human health associated with the use and misuse of resin materials. It is vitally important that all the health and safety advice is adhered to at all times.

In addition to the resin materials, one must consider all those necessary for the preparation of the moulds, eg wood or plaster sealers; wax and silicon release agents supplied in solid, liquid or spray form.

Good and careful preparation of a mould is essential if quality results are to be achieved.

Polyurethanes are supplied either as a two part mix or with the filler supplied separate from the liquid. The tins used contain the liquids in the correct mixing proportions and require only for the hardener to be poured into the filler resin and thoroughly mixed.

The major difference between polyurethane and epoxy resin is the speed of cure. Fast cast polyurethanes can take as little as one hour to solidify and be demoulded. This can be an

advantage to the patternmaker in certain instances. However, in order to reach this fast cure time, heat must be generated within the mixture (exotherm). The patternmaker must consider the effect that this excessive heat may have upon the surface finish of the mould and must devise ways of minimising its effect. The other disadvantage is contraction. The faster a mixture cures the more likely the contraction will increase. For most types of work a patternmaker needs zero contraction.

However, with the knowledge of this problem, the patternmaker can take counter measures to minimise it. The problems surrounding the use of epoxy resins and polyurethanes will be explored later when practical examples are considered.

e) Metals

The hardest of all the materials with which a patternmaker has to work is metal. The main ones being iron, aluminium, steel and bronze.

Iron is normally cast to a form using a wood master pattern. The iron pattern is then machined all over and finished by hand to the required surface quality. Iron is also used in the form of round bar and rectangular flats. The quality of iron is graded according to its tensile strength and elongation.

Aluminium is also cast to form a master pattern and is graded according to its quality and mechanical properties. An aluminium pattern may be machined all over if a close dimensional tolerance is required, but being a softer material than iron, it can be worked by hand tools more easily.

Bronze – some foundries prefer their patterns to be made of bronze or of a similar alloy. These metals can be difficult to work by hand and require machining over.

Steel – on occasions may be requested in a cast form but most patternmakers will use steel in the form of round or flat standard drawn bar. A patternmaker must understand the properties of each of these metals, their strengths and weaknesses, how to machine them, how to hand tool them, how to achieve the required surface finish and how to apply any treatments to improve the stability, surface finish and working life of the pattern.

9.5 Factors Affecting the Design and Construction of Pattern Equipment

When the patternmaker is faced with the question of how best to design the pattern equipment, he must be able to identify a number of important factors. These include:

a) How Many Castings are Required

If the answer to the question is say one or two, then a loose wood pattern, made as cheaply and simply as possible, will suffice. If, however, the answer is one or two thousand, then a multiple number of patterns will be required, made of resin or metal and mounted on boards or plates for machine moulding.

b) How Often is the Pattern to be Used

If, as stated above, only once or twice, but at regular monthly intervals, over many years, then one needs to consider the durability of the pattern construction and the need to remain stable, accurate and serviceable throughout the storage period.

c) What Tolerance is being Asked for

If the tolerance required is less than ± 0.2 mm, this cannot be achieved by the use of hand tools only, nor can it be measured accurately with a rule. Machinery must be used to size the piece accurately, instruments with vernier scale will be needed to measure the accuracy and resin or metal will need to be used in order to maintain the accuracy.

d) What is the Best Way to Construct a Pattern

Generally speaking this will depend upon the size and configuration of the pattern.

- Small patterns may be cut out of one of solid wood.
- If a pattern or part of a pattern is thicker than standard timber sizes, it can be built up in layers (laminates) taking notice of grain, possible warpage and shrinkage.
- A circular pattern will be built up in rows or layers of curved segments in order to give strength and reduce shrinkage.
- A large box section pattern will be constructed on a jointed framework and clad on the outside with plywood or blockboard, leaving the inside hollow. This will give the pattern strength stability and reduce weight and the amount of timber used.
- More complex large shapes may be constructed by laying strips of wood over shaped formers.

e) How is the Pattern to be Moulded

By making a detailed study of the drawing, with a mould joint in mind, a patternmaker will be able to design a one piece, flat back pattern, or a two piece split pattern, or even a three piece split pattern. The patternmaker will decide upon the position, size, shape and setting

of any coreprints required and how these may affect the mould joint. A decision must be made as to whether the pattern will be supplied loose, or mounted on boards with a runner system.

f) Will Cores be Necessary

In most cases the answer will be obvious to the patternmaker because there will be cavities or inside shapes to cast. But sometimes cores can be an alternative method of moulding an awkward shape or improving the stability of a pattern. Remember, however, that the manufacture of cores costs money and therefore adds to the cost of the casting.

g) What Method of Core making is to be Used

Will a simple hand-rammed wooden corebox be acceptable or must the corebox be designed to fit a coreblowing machine? Will the corebox require venting or ejection? The casting may call for more detail internally than externally. The corebox therefore may be made to a higher level of accuracy than the pattern. The surface finish of the cored cavity must also be considered.

Because of the variation in size, shape and complexity of a casting, this cannot be a definitive list of questions to be asked, but it should be an indication of the decision making process that must take place before the design stage can begin.

h) Typical Sequence of Events

- 1 Read drawing – seek any clarification necessary.
- 2 Collect information about customer or foundry requirements.
- 3 Decide on a design for the pattern tooling.
- 4 Produce a set out – full size.
- 5 Decide on a method of construction based on the set out.
- 6 Prepare a timber cutting list.
- 7 Plan sequence of operations of manufacture.
- 8 Prepare basic timber requirements.
- 9 Order any special parts or materials that may be required.
- 10 Proceed with production.

- 11 Finish tooling and apply protective coating (varnish, etc).
- 12 Submit completed tooling for inspection.

9.6 The Use of Plastics in Patternmaking

Plastic is a synthetic material made from the bi-products of coal and petroleum. The word 'plastic' is used to denote a material that can be formed into products by moulding or otherwise shaping. The distinction between plastics and resin is arbitrary since today's synthetic materials can be called both plastic and resin.

There are two main groups of resin:

- Thermo-setting resins
- Thermo-plastic resins

For the purposes of patternmaking, we shall concentrate on the first group only, thermo-setting resins, of which epoxy resins and polyurethanes are widely used.

Epoxy resins have outstanding mechanical and electrical properties, dimensional stability, resistance to heat and chemicals and adhesion to other materials. They are used for casting, protective coatings and adhesives for reinforced moulding and laminates of high quality.

Polyurethanes are formed by the reaction between di-isocyanates and polyols. Polyurethanes are among the most versatile of plastics ranging from rigid to elastic forms.

Because there are many variations of these two particular resins, produced by manufacturers, we shall refer to them by their generic name only and leave the manufacturers to emphasise the special merits of their products. To be successful in the use of either of these two resins will require some specific detailed knowledge and a level of competence supported by experience.

Each resin is supplied in a liquid form and will require mixing with a hardener and sometimes a filler. Below are listed some of the main elements of knowledge and competence that will be required when making any products from these resins.

9.7 Mounting of Patterns

Before this operation can be carried out certain information has to be sought from the foundry.

- Type of moulding machine to be used.

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- Type and size of mould board required to fit the machine.
- How will the board be fixed to the machine – clamped to the table or fitted into a permanent bolster?
- Size of moulding box to be used. This will give us the maximum area into which the patterns must fit, leaving adequate area for sand all around the patterns.
- Moulding box pin centres – are pins to be fitted to the moulding boards or are they already fitted to a standard bolster?

These are some of the questions that the patternmaker must ask and must be answered.

Having collected all the relevant information, the patternmaker can begin to construct the moulding boards and lay out the patterns (refer to layout drawing).

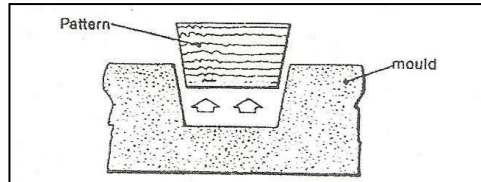
The pair of boards can be made of plywood and cut to the size and shape required. The boards will be larger than the moulding box to allow for it to sit on the board located by its pins. All the marking out therefore must be related to the pin centres and must be transferred from one board to the other to ensure a perfect pattern match, having established the centre lines of the patterns, they can be positioned and a line scribed around the profile of the pattern plinth. This will give us the shape of the recesses to be cut into the boards to bring the pattern join in line with the face of the moulding board.

The patterns are firmly screwed in position, from the back, using countersunk machine screws, into the thickest sections of the pattern. A suitable amount of space has been left down one side of the layout to provide an area for the runner system to be fitted.

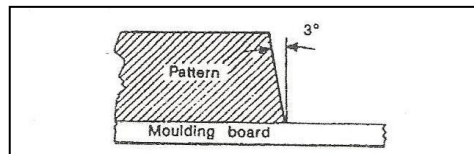
Exhibit CM

Taper/Draft Angle

Purpose and type

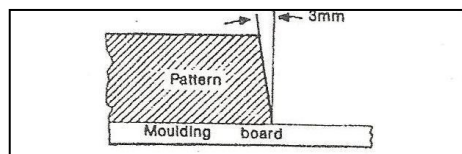


This is the angle or slope on the vertical sides of patterns and coreboxes, which is provided by the patternmaker to assist the clean and easy withdrawal of the pattern from the moulding material.

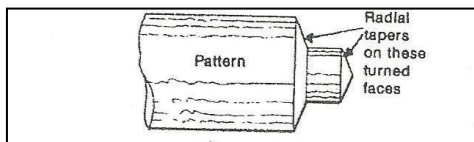


Taper is dimensioned by:

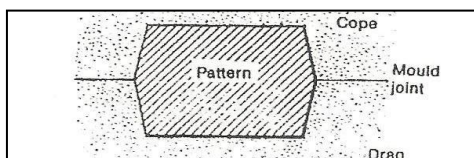
- Angular measure (degrees)



- Linear measure (millimetres)



On circular patterns the taper may be turned on the lathe. In this case the taper is referred to as radial taper.



The direction of the taper is governed by the position of the mould joint. The pattern is always larger at the mould joint.

10.0 QUALITY ASSURANCE

10.1 Quality Systems

If one is really honest, can it definitely be said that everyone in a foundry knows exactly what they are doing? Are all employees instructed on how to carry out jobs or is there a dependence on the experienced and personal knowledge of specific individuals? If so, what happens when such people leave, retire or die?

Pursuing the self-examination a little further – is there knowledge and analysis about the things that do go wrong? How much re-work is done? How many castings are remelted without being recorded? Is the value of internal scrap and re-work fully appreciated and what about customer returns? Here the cost of doing it wrong the first time, replacing the defective casting with (hopefully) good ones and still running the risk of losing repeat orders because of poor performance, needs to be counted.

Further, how much time and mental energy is spent ‘fire-fighting’ instead of running operations in a professional and business-like way?

To add to the workload, customers are demanding documentary evidence that the castings supplied have been made properly. This implies the keeping of records on all aspects of operations. It is not enough to do things properly – it needs to be shown that it is so!

No matter how good a foundry thinks it is, there will always be room for improvement. In the competitive world of castings manufacture it is necessary to adopt a more vigorous management style which allows the offer of advantages of price, delivery and quality to customers whilst improving profitability.

At this point some doubts and prejudices may creep in. It may be considered that the formalisation may be a nuisance, restricting operations and generating lots of extra paperwork for no apparent reason.

It may be necessary to employ a quality manager so that on-costs increase. Small orders may appear to become uneconomic because of the high administrative costs.

Anyway, why should anything be changed? After all is not the foundry industry too complicated to be defined in simple terms – it depends on years of experience, not formal written instructions. The list of such objections can be endless – but are they justified?

a) Reasons for Formal Quality Systems

Consider some sound practical reasons for introducing a formal quality system:

Financial Gain

Improved profitability clearly results from reduced scrap, rejections and re-work. It is often all too easy to recognise these improvements as the only benefits resulting from the installation of a formal quality system. Whilst these are important advantages, directly enhancing the 'bottom line' of the balance sheet, the true financial benefits are wider and less tangible.

How should the value be assessed of enhanced reputation arising from reduced customer rejections, from improved delivery performance which we expect to result from reduced internal rejections, re-work and the consequential disruption of production schedules? The true value of enhanced reputation cannot be calculated accurately, but it is potentially greater than the value of the improved internal scrap losses.

How is the increased production capability created by reduced scrap, re-work and re-make to be valued? This is possibly easier, especially if it can be used to increase output or if it saves capital investment otherwise required to generate that capacity. Perhaps more difficult to value is the expected reduction in maintenance and service costs related to the ability of the plant to produce a given level of output in fewer production hours.

How does one cost the savings of management time and effort brought about by these improvements? Real financial gain should result from directing this time and effort into the positive activities of thinking, planning and improving the system yet further, rather than wasting it in the negative activities of crisis management.

It is worthwhile to at least 'estimate' the potential savings in the foundry by following the guidelines given in Figure CN.

Customer Confidence

Also important is the continuity of a professional and good humoured relationship with the customer, from which further opportunities and orders may be expected to result. Any good salesman will take full advantage of reject levels consistently better than those of his competitors. Cost advantages at the goods inward stage should be emphasised to potential customers. It can also be stressed that castings will give real advantages at the production line due to reduced breakdowns, stoppages and variability in product quality.

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Essentially what is being said is that consistent quality in full conformance with the customer's requirements produces a broad range of benefits. The major benefit must ultimately be that of customer satisfaction. Indeed customer satisfaction is the crucial factor from which the modern quality philosophy has been developed.

Market Pressures

If any foundry has not yet been subjected to the market, it soon will be. Sometimes these pressures are direct from the customer. More often they come from a chain reaction. The customer may not be prepared to give an order until he has proved to his customer that manufacture can be controlled. Typical demands start in the automotive industry, ministries, mining companies, oil industry and the list is growing fast. Although for 'in-house' foundries that is delayed slightly, it is inevitable that the parent company (and hence its foundries) will have to meet specific quality requirements.

Customers have various standards they require, but there is a common requirement (usually a minimum requirement) of a demonstrable quality system. The international quality standard ISO 9000 has been widely adopted, but in addition to this there is a further requirement of ISO TS 16949 for the automotive industry. There is a similar specific additional requirement for aerospace applications.

Less Trouble

Each and every day foundries are subjected to:

- irate telephone calls from buyers because they have failed to meet promised delivery dates
- customer returns which need inspection and either rectification or replacement
- poor control of incoming materials
- lack of adequate control systems, procedures and documentation.

Hassle of this sort simply diverts managers from the main jobs. It is unconstructive and wastes valuable resources.

Product Liability

As product liability legislation is likely to have increasing implications to foundries, particularly those foundries that are involved with the design and marketing of their own products, consideration will need to be given to the identification of potential risk factors and the prevention of the possible causes in the manufacturing process.

One method of proving that reasonable care has been taken to overcome these causes is to introduce a total quality concept throughout the foundry.

Such a system will need to be formally documented in the form of a quality assurance manual, quality control procedures and work instruction.

10.2 Management and Quality

a) Introduction

It is interesting to note that when questioned about quality systems, most senior executives would agree that there are many long-term advantages to be gained. This is not surprising since quality improvements offer a company one area where significant financial gains can be made in return for very modest investments. Indeed, it has been estimated that making castings 'right first time' can achieve savings of 20% or more of sales.

There can be no doubt that formal systems for quality assurance and quality control are here to stay. The modern market demands it and it has been demonstrated to be cost effective. Here an overview will be presented of exactly what will be involved in setting up a formal quality system to at least the level of ISO 9000 in a foundry and explicitly what action needs to be taken by the chief executive. It is necessary to start with a clear explanation of the nature of a quality system.

b) Quality Systems

A quality system is a logical and common-sense approach to working. It is the practical means of carrying out a policy – the company's policy.

When designing a company's quality system, it is not necessary to start from scratch because it can be based on a quality standard such as ISO 9000.

The ISO 9000 standard lays down the necessary skeleton of an all purpose quality system, gleaned from the experience of practising managers. It describes how the work should be structured, not what can and cannot be done – it's up to the company to decide what the job requires.

A common misconception is that ISO 9000 will restrict a company's room for manoeuvre. If it does, it has not been interpreted to best advantage. Whatever it is wished to do, can be done, provided that:

- what is to be done is written down;
- it can be demonstrated that what is written is being done;
- the requirements of the specifications and related technical schedules of ISO 9000 are met.

By achieving approval to ISO 9000 it is being said to the world that the quality system meets certain criteria recognised standards. It says nothing about the specified quality of the product other than it will consistently be made to the specification, with the least amount of trouble for the customer.

c) Management Responsibility

The overall responsibility for the quality of the product must always rest with the chief executive. Management's role is one of participation in and involvement with, a quality system where everyone's duties are clearly defined.

The chief executive of a company is the person who must shoulder ultimate responsibility for product quality and it is not satisfactory to abdicate this responsibility to a quality manager, or indeed any other colleague or consultant. In other words the company must have a commitment to quality. This commitment must, furthermore, be declared in the form of a quality policy statement. The chief executive must be prepared to support the quality manager actively in enforcing the quality system, possibly on occasions to the detriment of production. The basis of a quality system is a clear and concise definition of who does what. Indeed, it is difficult to imagine any well run company being able to function without a formal management structure which defines each key individual's responsibility.

There is a requirement that someone be given sufficient authority to represent the management's interest in quality in the foundry. This individual must report directly to senior management. Ideally there should not be a conflict of interest with production.

d) Quality Manuals

Quality manuals are the basic reference books for the company and in them will be recorded everything which relates to producing a quality casting, that is one that is 'fit for its purpose' and meets all the customer's agreed requirements.

Quality manuals reflect the quality system in a written form, such that:

'what is written down happens and what happens is written down'.

Quality manuals define how the company's quality policy will be carried out. For this purpose they should be explicit, concise and understandable to the people who have to use

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them. They should be readily available for consultation by those having responsibilities within the foundry and where necessary be available at the place of work. The manuals produced must be appropriate for the company.

Whilst the form and basic contents of manuals for foundries operating in the same sectors of the industry will be similar, it must be stressed that ISO 9000 does not set a fixed format. Nonetheless, the manuals must demonstrate that all relevant sections of ISO 9000 have been addressed. It is also important to appreciate that the contents are not carved from stone. They can (and must) be changed to allow them to evolve with changing circumstances.

The following approach, dividing the manuals into separate levels is to be recommended:

- I) A quality manual, which is the basic skeleton of the system, showing in general terms how the company operates, but giving no confidential information. It acts as a guide to the rest of the system and is often written in the same order as the paragraphs of ISO 9000. This approach makes sure that no paragraphs are missed – but can make the result a little odd to read, therefore be careful!

The management's structure of the company will have to be included as will the chief executive's quality policy statement.

- ii) A procedures manual which spells out the underlying principles and the responsibilities of each task that has any bearing on the quality of the product. These tasks can range from order and despatch procedures, through purchasing policy, to how to set up a core blower and calibrate a spectograph. The key points are:
 - They must represent the company's current practices.
 - They should be concise, unambiguous and easily understood by the persons who are likely to use them.
 - They should include only sufficient detail to familiarise a person with the job. Common tasks and checks must be listed, but they only include sufficient detail to enable a person having the necessary skills to carry out the job properly.
 - They should cross-reference wherever possible to save duplication.
- iii) Work instructions relate to specific activities, products or customers, such as laying down control checks, production conditions or special requirements, etc.

e) Records

It is in a company's own interests to maintain comprehensive technical and production records for problem solving and as a defence in product liability cases, as well as to satisfy ISO 9000.

ISO 9000 requires that the company be able to demonstrate, through inspection results and process control records, that the product has been made to the specification agreed with the customer. Adequate provision for the security of these records (including method and responsibility for their disposal in due course) must be recorded in the quality manual.

Maintaining the System

The chief executive will need to ensure that the system is enforced and that everybody is working to its laid-down procedures.

To ensure that procedures are observed and, more importantly, are working in a positive, productive way, 'audits' are necessary. The standard demands that this be done in a formal organised way, with appropriate recording of findings and corrective action. The auditor must be trained in auditing techniques.

To ensure that the chief executive is fully aware of all quality matters he should chair a meeting comprising a group of managers to routinely review the effectiveness of the system. This 'steering committee' should look at the results of internal audits, trends in customer complaints, supplier performance and internal quality problems, as well as the results of surveillance visits. Remember that surveillance visits will be made by your certification authority at regular intervals. It ensures that the company does not lose sight of the overall quality objectives and responds to changing circumstances.

f) Implementation

As a first step a suitable person will need to be appointed with the authority to co-ordinate the implementation programme. The detailed work can then begin using the following guidelines.

- Carry out an in-depth assessment of the existing situation within the company and compare it against the requirements of ISO 9000.
- Devise a realistic implementation timetable stating exactly what needs to be accomplished to fully implement the revised system.
- Take steps to resolve the short-comings.
- Itemise all the shortcomings and ensure that all the relevant managers and staff fully understand the problems and opportunities for improvement.

- Prepare the necessary quality manual, procedures and work instructions.
- Instigate a programme of staff education. Such education should be formally given, formally assessed and formally recorded.

Once the system has been fully installed and is working, a 'dry run' assessment should be undertaken objectively by the chief executive, or some independent third party.

Finally a formal application for assessment should now be made to a certification body such as Lloyds Register Quality Assurance (LRQA) or any other recognised and accredited organisation.

10.3 Quality Inspection

a) General

Testing, inspection and measurement are critical in each casting production process, beginning with pattern and die design, then mould making and coremaking, chemical analysis of heats and, finally, the finished castings themselves.

The key element of any inspection method is the ability to discriminate between imperfections. There is a finite transition region between the imperfection that has a high probability of causing a rejection and the imperfection that has a high probability of passing the inspection.

Increased inspection sensitivity may actually decrease the ability of an inspection system to discriminate between defective and sound material. Real inspections have a finite inspection uncertainty.

Rejection criteria variability is a problem in all large-scale inspection programmes. Careful standardisation and continual checks of the inspection system against standards are required to maintain constant rejection criteria. For methods that are strongly dependent on the judgement of individuals, it is particularly difficult even for the same individual to maintain the same rejection criteria.

b) Leak Testing

Traditionally, leak testing in the foundry industry has been used to ensure that leaking products do not reach the customer. But as manufacturers employ different materials and assembly methods, present trends show the increasing use of leak testing to satisfy quality and warranty considerations. Current customer requirements include more complex castings used in more demanding applications and made using faster production cycles. Full (100%) testing to verify integrity is increasingly required, especially when the casting is part

of a liquid or gas container. Early model leak testers were used primarily as Go/No-Go indicators, since either no actual leakage volume reading was available or the accuracy of the reading was suspect due to uncontrollable variables. Now, recent advances in leak detector technology make possible use of leak detector readings as a reliable quantitative measure of product quality and production processes control.

Historically, the growing need for shorter test times conflicted with the reliability and precision of leak readings and the ability to detect very small leaks. With proper choice of the leak sensor, however, it is now possible to gain faster test cycles, applying tighter leakage specifications without sacrificing accuracy.

Two basic methods of dry-air testing are available. One measures the rate of pressure change, and the other directly measures leakage mass-flow. In the pressure change method the test part is pressurised and then isolated from the pressure source. Any change in the part's pressure over time must be converted by calculations into a measure of leakage. This is where the uncontrollable variables, such as ambient temperature changes, draughts, test part deformity, or seal creep, can cause problems.

In the mass-flow method, the test part is pressurised, and any leakage is compensated for naturally by air flowing into the test part from the source. The amount of air that flows in to replace leakage flow is measured directly in standard cubic centimetres per minute (scm).

c) Liquid Penetrant Inspection

The liquid penetrant method of non-destructive inspection is a way to find discontinuities that are open to the surfaces of castings. The method involves utilisation of a penetrating liquid that is applied over the casting surface and enters the discontinuities.

Subsequently, after the excess penetrant has been cleaned from the surface, the remainder exuding or drawn back out of the flow is observed, indicating the presence and location of discontinuities.

The visibility of the small amount of liquid withdrawn from a discontinuity is greatly enhanced by the use of special additive in the penetrant – either a very bright dye or a proprietary compound – that strongly radiates visible light under invisible, near ultraviolet illumination, usually called ‘black light’.

Liquid penetrant inspection depends primarily on the penetrant's ability to wet effectively the surface of a solid workpiece by flowing over it to form a continuous and reasonably uniform coating. Capillary action draws liquid into discontinuities that are open to the surface. Frequently they are so small that they cannot be detected by an unaided eye.

Six basic steps make up the liquid penetrant inspection procedure:

- thorough cleaning of the casting to be inspected
- application of the penetrant to the casting
- removal of any excess penetrant
- application of an absorbent coating (called a developer) to the casting under observation
- visual inspection of the casting under black light and interpretation of indications, if any
- post-inspection cleaning.

The apparent simplicity of this non-destructive testing procedure can be deceptive, because operating experience has demonstrated that very slight variations in performing the penetrant process and subsequent inspection can invalidate the findings by failing to indicate all flaws. It has, therefore, become accepted practice for all penetrant inspections to be carried out exclusively by trained and certified personnel.

d) Magnetic Particle Inspection

Magnetic particle inspection, by definition, is a method of non-destructive evaluation to locate surface and sub-surface discontinuities in ferro-magnetic materials. Aluminium alloys, copper and copper alloys, lead, titanium and its alloys and austenitic stainless steels cannot be inspected by this method.

There are several basic steps in applying magnetic particle testing:

- preparation of the test surface
- magnetisation of the casting under evaluation
- application of magnetic particles
- inspection for indication of flaws
- demagnetisation of the casting being tested.

Ferro-magnetic materials include most of the iron, nickel and cobalt alloys. Many of the precipitation-hardening steels are magnetic after ageing but lose their ferro-magnetic properties above the Curie point temperature.

The magnetic particle method is a sensitive means of locating small and shallow surface cracks. Discontinuities that do not break through the surface may also be indicated by this method. The deeper the discontinuity lies below the surface, however, the larger it must be to provide a readable indication. Many variables affect the formation and appearance of the pattern displayed by the finely divided ferro-magnetic particles on the component's surface. These include:

- the method of magnetisation employed
- the size, shape and direction of the discontinuity

- the direction and strength of the part under test
- the method of applying magnetic powder.

Magnetic particles are available in several colours to increase their visibility. They may be either dusted on as a dry powder or flowed on as a suspension in some liquid. Fluorescent particles are used for special applications.

To use non-destructive testing effectively one must be aware of the limitations of the different methods. For magnetic particle testing, the following points are important:

- Discontinuities that lie entirely below the surface are not always detected.
- The magnetic field must be in a direction that will intercept the principal plane of the discontinuity.
- Demagnetisation is a necessary step following inspection and takes time.
- Experience and skill are required frequently to judge the significance of easily seen indications.
- Very heavy currents are required at times to examine very large castings.
- Care is necessary to avoid local heating and, possibly, burning of finished casting surfaces at the points of electrical contact.
- Paint or plating adversely affect the sensitivity of magnetic particle inspection.

There is little limitation on the size or shape of the casting being inspected. Other advantages of the method include the following:

- it is rapid and simple to operate
- there is no electronic circuitry or read-out to be calibrated or kept in proper operating condition
- indications are produced directly on the part's surface
- no elaborate pre-cleaning is necessary
- a skilled operator can make a reasonable estimate of crack depth with suitable magnetic powders and proper technique.

e) Ultrasonic Testing

Ultrasonic inspection uses beams of high frequency sound waves to detect surface and sub-surface flaws. The term 'ultrasound' refers to sound waves with frequencies greater than 20 kHz (20,000 cps), which is about the upper limit of sound frequencies audible to the human ear.

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In this type of inspection, sound waves travel through the material with a loss of energy (attenuation) and are reflected at interfaces. That reflected beam is displayed and analysed to determine the presence and location of flaws or discontinuities. Ultrasonic inspection is now a principal method of non-destructive evaluation. Only ultrasonics and radiography can substantially reveal sub-surface flaws. It is suited especially to determining characteristics of engineering materials.

The following are the principal advantages of ultrasonics:

- it has the ability to penetrate to substantial depths in many commercial materials
- it is sensitive to minute flaws
- it provides comparative accuracy in determining flaw size and depth
- as a result of electronic operation, it gives rapid, substantially automated inspection.

The process also has its disadvantages, including the following:

- Technicians must have considerable ability, training and experience.
- The process covers only a small area. Coverage of large areas requires complex mechanical scanning or the use of an array of numerous transducers.
- Its use requires a good, essentially mechanical coupling to the article to be tested.

Two basic types of ultrasound test systems are in use:

- resonance
- pulse echo.

Each has modifications and accessory systems, and there are at least four major types of signal display systems.

In resonance testing the transducer is driven by a sweep oscillator, the frequency of which varies continuously. When the natural frequency of the material thickness or a multiple of that frequency has been reached, the amplitude of vibration increases and produces a display on the cathode-ray screen.

Pulse-echo equipment drives the transducer at a single, pre-selected frequency for a fraction of a second. The sending crystal – or a second transducer, which is used only as a pick-up – listens for the return of the short burst of sound after it has travelled through the test material and has bounced back from a flaw or from the rear surface of the test object.

f) Eddy Current Testing

The basis of eddy current testing is the detection of quality problems by observation of the interaction between electromagnetic fields and metals. The process lends itself to automated production line testing.

An alternating current carried in a coil of wire induces eddy currents in the part being tested. As a part enters the coil, or as the coil probes the part, electromagnetic energy produced by the coil is partially absorbed and is converted into heat by the effects of resistivity and hysteresis.

Eddy current testing can be used with castings for a variety of purposes:

- to measure or identify conditions or properties including:
 - electrical conductivity
 - magnetic permeability
 - grain size
 - heat treatment condition
 - hardness
 - physical dimensions
- to detect
 - seams
 - laps
 - cracks
 - voids
 - inclusions
- to sort dissimilar methods and to detect differences in their composition microstructure and other properties.

Some variables in a material may produce signals that obscure critical variables or that are erroneously believed to be critical variables. The correlation between instrument readings and the structural characteristics and serviceability of parts under inspection must be established and checked repeatedly.

Compared with magnetic particle testing, eddy current testing is not as sensitive to small flaws, but it is effective with both ferro-magnetic and non-ferro-magnetic materials.

Ultrasonic methods are superior to eddy current methods for resolving small flaws and flaws well below the surface, but eddy current methods do not require mechanical coupling to the specimen.

Eddy current techniques are faster than radiographic methods, but usually are not as sensitive to small, deep, sub-surface flaws. Eddy current test equipment covers a range from simple units to fully automatic systems. All must incorporate certain elements:

- a source of magnetic field capable of inducing eddy currents in conductive materials
- a sensor or transducer sensitive enough to recognise minute changes in the magnetic field caused by eddy currents
- a means of interpreting changes in a magnetic field by:
 - monitoring a meter, the reading of which is proportional to the magnetic field change
 - an electronic 'black box' that displays readings proportional to phase, magnitude, or modulation of the magnetic field.

The eddy current method of casting inspection is, therefore, said to have the following advantages:

- under controlled conditions it provides an accurate measure of conductivity
- it lends itself to automation
- flaws and material condition are indicated immediately
- inspection can be performed at high rates
- the area of inspection can be reduced to find discontinuities as small as 0.00006 in
- mechanical contact with the test part is not usually necessary.

g) Radiography

Most industrial radiography of ferrous and copper castings up to 70 mm thick is performed with x-rays. It is highly effective and versatile and, with modern techniques, very accurate. In addition, radiography lends itself well to automated inspection systems.

The principal advantage of the alternative gamma ray radiography over x-ray radiography is its lower cost. In addition, the source can be very small so that transportability is easy. Gamma radiography is selected for castings over 70 mm or when the volume of testing does not justify the more expensive x-ray equipment.

In general, gamma ray radiography is not as sensitive to small defects as x-ray radiography in thicknesses under 1 in. In addition, gamma rays generally require a longer exposure time than to x-rays, and do not provide as sharp a definition.

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Over the last few years, several new radiographic techniques have been developed, including:

- Computer tomography (CT) which is descended from the computerised axial tomography scanner (CAT scan) and which provides a cross-sectional view of the workpiece.
- Neutron radiography, which, unlike the techniques already mentioned, uses neutrons rather than electromagnetic radiation. It has increasing application in inspecting castings.

Radiographic examination of castings can expose operators to harmful radiation if proper precautions are not taken.

One of the most dangerous aspects of radiation exposure is that the effects are cumulative. For this reason, strict regulations have been issued for lifetime accumulated dosage as well as annual dosage. Usually individuals are monitored over much shorter periods of time.

Although there are many ways of protecting personnel from radiation, the best is distance, since radiation intensity decreases with the square of the distance from the source. To protect those who must be in the vicinity of the radiation source, it is housed in a specially designed enclosure that is connected to various interlocks and failsafe devices.

All personnel in the restricted area must be monitored to ensure that they do not absorb excessive amounts of radiation. This is usually done by means of pocket dosimeters and film badges. Often both are worn. Since pocket dosimeters are sensitive to shock, they can give erroneously high readings. If this happens, the film can be developed to get a 'second opinion'.

Any facility using radiation should be manned by trained personnel only. Access should be strictly limited, and no one should be allowed into the area without appropriate monitoring devices. In addition, it is essential to maintain thorough and accurate dosage data on all personnel. Finally, careful monitoring of radiation levels must be carried out in and around the facility by component radiographers.

h) Visual Inspection

Most foundries employ visual inspection techniques, where operators visually check castings after final processing. Operator fatigue can mean, however, that defective castings can get through.

Developments are taking place with on-line visual inspection systems where each casting is 'photographed' and compared to a master. This is of most use where high volume

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repetition castings are manufactured and the finishing process can be designed to include this facility automatically.

Other visual methods include the use of endoscopes attached to TV monitors to allow operators to inspect inside castings, around internal angles, etc.

Exhibit CN Outline for Estimating Potential Annual Savings

1	Reduced internal costs from less-	
	(a) process scrap	£
	(b) rejections	£
	(c) re-work	£
	(d) re-make	£
2	Reduced external costs from less –	
	(a) customer rejects	£
	(b) re-work	£
	(c) warranty claims	£
3	Reducing costs of managing -	
	(a) the investigation of customer complaints	£
	(b) crises	£
	(c) re-work	£
	(d) re-make	£
4	Improved customer reputation –	£
5	More efficient management – concentrating upon the positive activities of planning and strategy	£
6	Company confidence and morale	£
ESTIMATED TOTAL COST SAVING		_____
