Improving yield and reducing costs in foundry operations
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This Good Practice Guide was prepared by Envirowise

Prepared with assistance from:

McLellan and Partners Limited
In today’s competitive environment, no foundry can afford to pass up the opportunity to improve yield. Producing more good castings from the same amount of metal melted makes sound business sense and will realise many benefits, including:

- reduced use of resources;
- less waste;
- lower energy costs per casting;
- reduced labour costs per casting;
- fewer customer returns and hence better customer relations;
- higher profits.

This Good Practice Guide defines yield and introduces various techniques, technologies and tips that will help foundries casting grey iron, ductile iron, aluminium alloys and copper alloys into sand moulds to improve their yield and thereby their business performance.

The first step in any yield improvement programme is to gauge current performance. This Guide describes what this involves and contains guidance on how to construct a metal balance, which will identify where metal is currently being lost. The balance will also highlight the key areas for action to improve yield. Using the information in this Guide will help you to take any necessary action and realise the benefits of higher yield operation.
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This Guide discusses a range of techniques and technologies that can help foundries casting grey iron, ductile iron, aluminium alloys and copper alloys into sand moulds to produce more good castings and thereby improve their yield.

UK foundries cast over one million tonnes of metal each year (see Table 1), with a total value of over £1.1 billion (2002 figures). Improving the yield can improve the productivity of a foundry and reduce unit costs. Moreover, producing more good castings for the same amount of metal melted will increase the value of sales relative to fixed costs, increasing profits. In instances where specification ingot is bought in and scrap is not remelted on site, the potential savings in material costs may also be significant.

Every foundry should aim to achieve the lowest possible defect rate. Making it right first time will maximise yield.

**Table 1 Approximate annual production of UK foundries**

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<th>Casting type</th>
<th>Annual production (tonne)</th>
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<td>Cast iron (including ductile iron)</td>
<td>880 000</td>
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<tr>
<td>Light metals (aluminium and magnesium)</td>
<td>185 000</td>
</tr>
<tr>
<td>Other non-ferrous (mainly copper alloy)</td>
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**1.1 The importance of yield**

Yield is usually defined as the total weight of good castings expressed as a percentage of the total weight of metallic materials melted to produce them, ie:

\[
\text{Yield (\%)} = \frac{\text{Total weight of good castings}}{\text{Total weight of metal melted}} \times 100
\]

Yield varies considerably from one foundry to another, depending mainly on the type of casting produced and the type and grade of metal concerned. For example, a typical grey iron foundry will operate with an overall yield of approximately 65%, ie for every 100 tonnes of metal charged, the foundry will produce 65 tonnes of saleable castings. However, foundries producing specialised grey iron castings may achieve a yield as high as 90%. In foundries producing malleable iron castings, yield may be only 35 - 45%, while in those producing ductile iron a yield of 50 - 70% is typical.

Significant savings can be made by improving yield. For example, if a foundry that normally produced 50 tonnes of good castings from every 100 tonnes of metal melted could increase its yield to 60%, it would only need to melt around 83 tonnes of metal to produce the same amount of castings. This would save £500 - £1 000 in melting energy costs alone. Put another way, output could be increased by 20% without increasing melting costs. Furthermore, if part of the yield improvement resulted from a reduction in the number of defective castings, there would also be benefits in terms of lower labour, consumables and overhead costs.
1.2 The benefits of good foundry practice

Achieving high yield depends largely on the application of good foundry practice.

For example, in the 1980s, the introduction of ceramic foam filters for molten metal realised significant improvements in yield, by simplifying running systems and reducing the incidence of defects caused by oxidation and other non-metallic inclusions.

For small or shallow castings in aluminium and ductile iron, a foam filter with an insulating feeder sleeve, into which the metal is poured directly, can replace a conventional running system. This ‘direct pour’ technique can result in substantial yield improvements.

Foundries can also improve yield by applying good practice that will:

- minimise oxidation losses;
- deliver metal to the moulds in good condition, within specification and at the required temperature;
- avoid metal spills and minimise pigging of surplus or off-specification metal;
- pour the correct volume of metal into each mould and not over-fill the pouring basin;
- correctly dimension sprues, runners and ingates, to run full and prevent turbulence and air entrainment;
- correctly dimension feeders, using insulating or exothermic sleeves to minimise their volume;
- eliminate feeders where not absolutely necessary.
Before a foundry can take any action to improve yield, it needs to know what its current yield is and in which areas most metal is lost, to highlight key areas for action.

### 2.1 Looking at the production stages

Actual yield is always less than 100%, because the weight of metal melted always exceeds the weight of good castings dispatched. Foundries should aim to achieve as high a yield as is realistically possible.

The various stages involved in the progress of metal from melting to dispatch of casting are shown in Fig 1. At each of these stages, metal may be either irretrievably lost or else be rerouted through the foundry, both of which will impact on the yield achieved.

**Fig 1 Mass balance - metal progress from melting to casting**

Non-recoverable losses occur during:

- the melting operation - through oxidation, slagging and drossing operations, production of test pieces, and so on;
- distribution and pouring - through oxidation and as spillage;
- fettling - as metal dust or material ground-off castings.

These losses typically amount to between 5% and 10% of the total metal melted, and represent a significant cost when the value of metal, energy and labour input is considered.

Recoverable losses account for the rest of the excess melted metal. These losses include pigged metal, running systems and scrap castings, all of which are generally returned for remelting. Although the metal is recovered, these losses still reduce the yield and add to costs in terms of melting/remelting energy and associated labour and overheads.

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1 For aluminium castings where pressure tightness is essential, scrap is often returned to the secondary smelter for reprocessing. This enables the metal to be separated from the thick oxide layers arising during casting and, if necessary, enables correction of the alloy composition, by replacing elements lost through oxidation or vapourisation.
2.2 Preparing a metal mass balance

Before the yield of good castings can be improved, the existing yield must be accurately determined.

- Draw a diagram similar to that shown in Fig 1, including all stages involved in the production of castings. If different metals or alloys are cast, or more than one moulding process is used, draw a diagram for each, to enable calculation of the individual yields.

- Record on the diagram(s) the weight of metal melted, the weight of castings dispatched, and any customer returns over a set period of time. Each of these items must be accurately measured.

- Record the quantities of metal lost and the points in the process at which they occur. Again, accurate measurements are required.

- Collate all the information to derive a metal mass balance for each metal or alloy being cast, and for each moulding process.

- Divide the weight of castings dispatched by the total weight of metal melted and multiply by one hundred to work out the yield.

- Look at the areas where metal is lost and prioritise them for action, starting with those areas with most losses.

- Once action has been taken, repeat the exercise to monitor progress and maintain the improvements.
This section describes the properties of molten metals and their behaviour during solidification. It highlights the interactions between molten metals and their environment which, if not controlled or allowed for, will lead to defects in the solidified casting. It is important that foundries are aware of, for example, the properties of metals they cast, and take them into account when modifying any processes. In addition, the properties may help identify reasons for metal loss or defective castings, highlighted when preparing a metal mass balance.

**3.1 Fluidity, entrainment and casting defects**

**3.1.1 Molten metal**

Molten metal is highly reactive, reacting both with the gases it comes into contact with and the material of the furnace, ladle or mould that contains it.

Molten metal readily dissolves hydrogen, which can originate from combustion gases, water vapour in the atmosphere, or damp refractories. Some molten metals also dissolve oxygen or nitrogen. If not adequately controlled, dissolved gases will come out of solution during solidification, causing porosity in the casting.

Surface films can be formed from solid oxides derived from the metal itself or deoxidants, silica or silicates from alloyed silicon, and other impurities such as sulphides. If the metal flow is turbulent, the surface films get folded into the melt during pouring and filling of the mould and may form lap defects or cracks in the solidified casting.

The critical fall height to avoid surface turbulence is only about ten millimetres for the common casting metals, but in conventional casting operations, pour heights (from the ladle into the pouring basin and within the running system) are much greater than this. In practice, for fall heights up to about 90 - 100 mm, the surface film has a stabilising effect on the falling stream, preventing surface turbulence, and the film accumulates smoothly as a ring of dross on the receiving molten metal surface. At greater fall heights, or if the pouring velocity is high, the surface films gets submerged and air gets entrained in the melt; these then become defects in the solidified casting.

**3.1.2 Fluidity**

In foundry usage, fluidity is the maximum distance to which metal will flow in a mould before it solidifies. It is usually defined in terms of a standard mould of constant cross-section.

Clean melts have greater fluidity. Fluidity is substantially reduced by oxide films and other solid debris entrained in the melt.

The fluidity of pure metals and eutectics that solidify at a particular temperature is greater than that of other alloys that solidify over a longer temperature range. Pure metals and eutectics solidify with a clearly defined plane interface between the solid and the liquid, and flow ceases when the freezing fronts meet in the middle of the section.
Longer freezing range alloys solidify in the form of crystal dendrites which grow from the mould wall. The flow of metal breaks the dendrites away from the wall, creating a slurry of dendritic crystals in the remaining liquid. When the concentration of dendrites reaches a critical level, they start to interlock. The resistance to flow then increases rapidly, and flow ceases.

Eutectic alloys have a greater fluidity than long freezing range alloys of the same elements, because of this difference in solidification behaviour. Fluidity also increases with increasing superheat of the melt. At a given temperature, a eutectic has a higher superheat and a greater fluidity than other alloy compositions of the same elements because of its lower melting point.

The pouring temperature must always be high enough for the fluidity of the molten metal to be sufficient to fill the mould. However, increasing the temperature is not a solution to fluidity problems if they are caused by a lack of cleanliness of the melt. Higher melt temperatures will increase oxidation rates and gas solubility, introducing yet more defects.

3.1.3 ‘Turbulent-sensitive’ and ‘turbulent-insensitive’ metals

‘Turbulent-sensitive’ metals are those such as aluminium alloy or ductile iron, which produce solid oxide films on the melt surface. Running and gating systems must be designed such that there is no turbulence or splashing. Unless castings are very shallow, bottom filling of the mould is essential. Ingates should be located so the mould fills smoothly and continuously. The gating layout should be such that pockets in the mould, which would otherwise create ‘waterfall’ effects or turbulence during filling, are avoided or gated separately.

‘Turbulent-insensitive’ metals are those such as grey iron and gunmetal, for which the oxides are either liquid at melting temperature or produce a liquid slag. They can tolerate higher velocities or greater pour heights, as oxides and slag particles are able to float out of the liquid metal and are much less liable to cause defects in the casting.

3.2 Properties of common casting metals

3.2.1 Grey iron

Grey iron is relatively tolerant of surface turbulence, because the surface film is liquid at the critical late stage of pouring when the temperature of the liquid metal falls. If the surface film becomes entrained in the molten metal, it will agglomerate to form droplets of liquid slag, along with other non-metallic inclusions. As these slag droplets have a lower density than the iron, they will float out and spread over the molten metal surface. Provided that quantities are not excessive, the integrity of the casting will not be affected. Any droplets remaining in the body of the casting on solidification will be spherical and will have little detrimental effect on the strength of the casting.

Carbon in solution precipitates as flake graphite during solidification. Because graphite has a much lower density than iron, this causes ‘eutectic expansion’. Grey iron forms a heavy outer skin during solidification which resists this expansion. Excess liquid iron can be displaced to areas requiring feeding. For this reason, grey irons tend to require less feeding than other metals.

3.2.2 Ductile iron

Magnesium is added to liquid iron as a nodularising treatment. As the melting point of magnesium oxide is above the temperature of liquid iron, oxidation of the magnesium produces a solid dross layer. If this layer becomes entrained in the melt, the magnesium oxide will react with silicon and oxygen to produce magnesium silicate films. These films can produce surface defects or, more seriously, form a crack in the casting. Surface turbulence in the running system must be controlled to avoid these types of defects and maximise the yield of good castings.
The solidification behaviour of ductile iron is more difficult to predict than that of grey iron. Ductile iron solidification is characterised by a relatively thin skin and often a ‘mushy’ zone, containing a mixture of metallic crystal dendrites and liquid iron. This restricts the displacement of the remaining liquid to areas requiring feeding during the ‘eutectic expansion’. Consequently, the feeding of ductile iron castings is more difficult than that for grey iron.

3.2.3 Aluminium alloys

Molten aluminium readily oxidises to form aluminium oxide, which is refractory and forms a thin solid film on the liquid surface. The oxide is of similar density to the metal and does not readily float out if it becomes entrained by turbulence during pouring and filling. Thin films of oxide form crack-like defects. In thin castings these cracks can often extend right through the wall, reducing mechanical strength and rendering the casting unfit for any application requiring leak- or pressure-tightness. Oxide particles also form nucleation sites for gas bubbles, leading to porosity in the solidified casting if the melt has not been adequately degassed. For aluminium alloys, the cleanliness of the metal entering the mould is very important if a high yield of good castings is to be obtained.

Aluminium-magnesium alloys can be particularly difficult to cast, because a mixed oxide (spinel) or magnesium oxide builds up rapidly on the melt surface. If folded into the melt, magnesium oxide films become a major source of defects in the solidified casting.

3.2.4 Copper alloys

Copper alloys are generally free of oxide film problems, unless the concentration of oxide exceeds its solubility limit in the metal close to the surface. Surface oxide films can occur when alloying elements possessing refractory oxides are present in the melt. Graphite surface films sometimes occur under the carbonaceous atmospheres generated by some organic sand binders.

Aluminium bronzes and some high strength brasses containing aluminium are difficult to cast, because the aluminium content and the high casting temperature together produce a thick oxide film. The oxide film reduces fluidity and is a potential source of defects in the casting if it becomes entrained by turbulence during pouring and filling of the mould.

Because copper readily dissolves both hydrogen and oxygen, melting should preferably be carried out in a controlled, dry environment. Potential sources of dissolved gases include furnace gases, damp refractories or charcoal. Deoxidation and degassing practices are both important to avoid porosity in the solidified casting.

Brasses and the manganese bronzes are less prone to porosity problems, because the vaporisation of zinc from the melt surface has a degassing effect. The zinc vapour also acts as a barrier, preventing absorption of furnace gases into the melt. A small amount of zinc may have to be added before pouring to compensate for that lost by vaporisation.

Some copper alloys, such as the bronzes, have a long freezing range. These alloys are difficult to feed and are prone to centrepiece shrinkage defects. The use of chills, incorporated in the moulds to create steep thermal gradients and promote directional solidification, can help achieve satisfactory feeding.

Copper alloys containing very high levels of lead feed rather better, because the lead has a low solubility in the solidified alloy and remains liquid long enough to seal the micropores within the dendrite mesh. Such alloys have traditionally been used where pressure-tight castings are required but, with increasingly stringent regulatory requirements, are being replaced by less toxic alloy compositions.
Foundry practice with regard to metal holding and treatment techniques can have a significant impact on yield.

High yields of good castings can only be obtained if the molten metal is in good condition, within specification and at the correct temperature when delivered to the pouring stations. This is achieved primarily by the application of good melting practice, with particular attention to the following:

- correct tapping and pouring temperatures;
- adjustment of composition to specification, if necessary;
- good inoculation practice (iron);
- avoidance of fade following ductile iron treatment;
- flux treatments to remove oxides (aluminium);
- effective degassing (often essential for non-ferrous metals);
- deoxidation practice (copper alloys).

This section looks at all these areas and outlines good practice in molten metal handling and treatment. Several case studies are included, which highlight the benefits that can result from using the best techniques.

### 4.1 Tapping temperature

Metal is often tapped from the melting or holding furnace at a temperature higher than the optimum for casting, to compensate for inadequacies in the molten metal handling, treatment and distribution systems.

Considerable energy savings can be made by:

- minimising heat losses;
- ensuring that the time from tapping the furnace to pouring the moulds is no longer than necessary, taking into account any requirements for metal treatments and dispersion of inoculant.

Avoiding unnecessarily high temperatures will also help to improve yield by:

- minimising oxidation losses;
- reducing the potential for the formation of porosity defects in the castings, as gas solubility increases with higher temperatures.

### 4.2 Holding

Holding furnaces are used where large continuous melting plants are in use, such as cupolas for iron or tower furnaces for aluminium. A buffer supply of molten metal is often required where mechanised moulding lines are in use, to ensure continuity of production. Holding units also allow ferrous foundries to produce a range of metallurgical specifications from a common base metal by varying the additions or treatments.
There are several types of holding furnace in use. Coreless induction-type holding furnaces can be used for compositional adjustment or alloying. Automatic pouring units are usually based on channel-type furnaces, which have the advantage that they are usually closed or fitted with swing or removable lids, thereby allowing some control of the furnace atmosphere and minimising metal losses through oxidation.

Some treatments, such as desulphurisation of iron, result in a significant loss of temperature. In these cases, subsequent superheating in a holding furnace may be required to reach the correct casting temperature. However, intermediate holding and superheating furnaces require a constant supply of energy merely to maintain a uniform temperature and are, therefore, expensive to operate, particularly in a single shift operation.

For smaller throughputs it is usually more economic to melt, adjust composition, de-gas and alloy in the melting furnace, and then carry out any other treatments required in-ladle or even in-mould.

### 4.3 Metal distribution

Molten metal has to be transported to the pouring stations, sometimes over considerable distances. Any intermediate treatments, and sampling and testing procedures, also increase the time between tapping and pouring, increasing temperature losses.

Carefully plan the foundry layout and metal distribution system to minimise the time delay between tapping the melting furnace and pouring the moulds. In addition, avoid unnecessary transfers of metal from one ladle to another, to minimise temperature losses.

### 4.4 Ladle practice

#### 4.4.1 Ladle lining systems

Ladles require effective lining installation, maintenance and preheating to prevent contamination of the metal and maintain their temperature. Ladles were traditionally lined with ganister or alumina-based materials in plastic and castable form.

More recently, preformed linings have become available for lip pour and teapot spout ladles (Fig 2). Refractory board systems are available which can be used to prefabricate linings outside the ladle.

The improved insulating properties of the refractory board materials reduce heat losses and are claimed to reduce or eliminate preheat requirements. In addition, these new materials have made breakout of solidified slag and old linings easier and less labour intensive.

#### 4.4.2 Ladle covers

Radiation from the molten metal surface accounts for as much as 50% of the heat lost from the metal held in casting ladles.

If a ladle is kept full for any length of time before pouring, equip it with a well-fitted refractory-lined cover.
Covers also reduce heat loss from empty ladles, reducing thermal stress on the refractories and metal temperature loss when next used.

### 4.4.3 Control of slag or dross

Slag or dross floats on the surface of the molten metal. Prevent it from entering the mould by using a skimmer or ‘teapot spout’ ladles incorporating a refractory dam before the ladle lip or a bottom pour ladle (Fig 3). A disadvantage of the ‘teapot spout’ ladle is that the narrow spout is prone to blockage with solidified metal or slag, particularly if the pouring period is long.

![Fig 3 Ladies designed to retain floating slag or dross](image)

It is also possible to use automatic pouring units with bottom pour systems with a stopper and pouring hole (Fig 4). A disadvantage of these units is that the static head above the pouring hole generates a high velocity in the metal stream, creating turbulence in the pouring basin of the mould.

![Fig 4 Automated pressure pouring vessel](image)
4.5 Additions and treatments

Molten metal is generally subjected to many additions and treatments, to improve its properties and/or remove impurities, with the intention of reducing metal losses, reducing defect rates and producing more good castings. Choosing and applying the right techniques is key to improving yield.

4.5.1 Cast iron

Desulphurisation

Desulphurisation is essential for the production of ductile iron, and is often justified in the production of grey iron in order to reduce the occurrence of manganese sulphide segregation and associated sub-surface blowholes.

A base metal with low sulphur and high carbon content is required for the production of ductile iron. Any sulphur present reacts with the magnesium used for nodularisation, reducing its effectiveness.

Sulphur is removed by thoroughly mixing the desulphurisation agent (calcium carbide or lime) with the iron in a treatment or reaction vessel on either a batch or continuous basis. Carbonisation to the required level can be done at the same time if necessary. As the absorption of carbon by molten iron is endothermic, the temperature falls by 70°C for each 0.1% increase in carbon.

Inoculation

Inoculants are added to molten iron just before pouring, to promote the precipitation of graphite and prevent the formation of white iron or carbide structures. Graphite or silicon-rich materials are effective inoculants for grey iron, while inoculants for ductile iron are based on silicon-rich materials, such as ferro-silicon.

The effectiveness of ferro-silicon inoculants is enhanced by the addition of small amounts of reactive metals such as calcium, magnesium and aluminium and, for particular applications, strontium, barium, zirconium or cerium.

Chemical reaction or vaporisation of the inoculants rapidly reduces their effectiveness, so they are best added to the molten metal as late as possible. Inoculant can be:

- added to the ladle (after magnesium treatment for production of ductile iron is completed);
- placed in the bottom of the pouring ladle before transferring metal into it;
- directed into the metal stream in automatic pouring systems just before entry into the pouring basin, using compressed air or a filled wire system.

In-stream inoculants require a sufficiently high silicon content to be exothermic when going into solution, to assist their rapid absorption.

It is also possible to place tablets of inoculant in the running system of the mould, as long as there is sufficient distance between the print in which the tablet is located and the ingate to ensure that the inoculant is uniformly distributed throughout the metal.

Ductile iron treatment

The temperature of molten iron is well above the boiling point of magnesium, which has a vapour pressure of about 8 bar at usual pouring temperatures. As the magnesium vaporises the nodularising effect is diminished, a phenomenon known as magnesium fade. Magnesium is also lost by reaction with oxygen and sulphur in the melt and with atmospheric oxygen, forming a slag of magnesium oxide and magnesium sulphide.
It is not possible to increase the pressure in the treatment vessel or holding furnace sufficiently to prevent magnesium vaporisation, but the rate of loss can be slowed by increasing the metal depth, avoiding contact with air and pressurising the vessel with an inert gas, usually nitrogen. The use of nitrogen minimises oxidation and sulphur reversion reactions at the liquid surface. Even so, treated metal can be held for only a short time before fade occurs.

**Sulphur reversion**
Magnesium sulphide reacts with oxygen in the air to produce magnesium oxide and elemental sulphur. The sulphur redissolves in the melt and reacts with more magnesium, increasing the rate of magnesium fade. In-pour or in-mould methods of treatment can tolerate somewhat higher sulphur contents in the melt, as the time between treatment and solidification is minimised.

**Ductile iron treatment methods**
Various techniques are available, most based on the use of magnesium-ferro-silicon alloy. Nickel-magnesium alloys are also used for some specialised applications, while magnesium metal is used in some high volume applications. The main techniques are described here.

- **Tundish ladle cover**
  Molten iron is tapped into a tundish ladle cover from which it falls onto the treatment alloy in the bottom of a deep ladle. The tundish ladle cover minimises the escape of fume and reduces heat losses.

- **Sandwich**
  A deep ladle is equipped with a dam in the bottom. The treatment alloy is placed on one side of the dam and covered with steel scrap. Molten iron is then poured into the other side of the dam and allowed to flood over, submerging the treatment alloy as rapidly as possible. Fume is suppressed by using a ladle cover.

- **Plunging**
  The treatment alloy is secured in a plunger bell which is then submerged in the ladle.

- **Porous plug**
  The molten iron is agitated by the injection of nitrogen gas through a porous plug in the bottom of the ladle while powdered treatment alloy is added.

- **Injection**
  Powdered treatment alloy in a carrier gas stream is injected below the metal surface using a hollow lance.

- **Converter methods**
  The treatment alloy is placed in a chamber within a closed treatment vessel. The main body is filled with molten iron and the vessel tilted or rotated to bring the iron in contact with the treatment alloy.

- **In-stream**
  Where automatic pouring units are in use, it is possible to carry out magnesium treatment during pouring using an automatically-fed filled wire system.

- **In-mould**
  The treatment alloy is placed in a chamber in the running system of the mould, where it is absorbed by the metal stream as the mould is filled.

**4.5.2 Aluminium alloys**

**Flux treatment**
Flux treatment promotes the separation of dross from molten metal, thereby improving the yield of clean metal from the furnace charge. The treatment substantially reduces the loss of metal during skimming of the dross. A layer of molten flux on the surface of the metal also acts as a barrier layer between the melt and the atmosphere.

Fluxes for use with aluminium alloys are usually based on a mixture of chlorides and fluorides.
Fluxes for application directly to the melt surface are usually supplied in granular form, rather than as powder. Granular fluxes are claimed to be effective at lower application rates and to reduce emissions of fluoride, by reducing losses into the furnace exhaust system. Use of the granular fluxes can, therefore, reduce emissions to atmosphere and also significantly improve the working environment in the foundry.

An alternative method of treatment uses an open-ended lance to deliver powdered flux using a nitrogen carrier gas (Fig 5). The flux agglomerates solid oxide films and particles floating in the melt which can cause significant defects in the casting, and they are then floated out by the nitrogen gas. The treatment will also remove dissolved hydrogen if very high levels are present because of a direct-fired furnace atmosphere, or perhaps from damp refractories. However, if melting has been carried out in an induction furnace, and the gas content is already in equilibrium with the workplace atmosphere, an open ended lance will not reduce the level of dissolved hydrogen significantly.

**Fig 5 Flux treatment of aluminium alloy**

Agglomerated oxides floating to melt surface

Powdered flux in nitrogen carrier gas

Large bubbles have little degassing effect

**Case study 1 - Foundry reduces reject rate through flux degassing**

A foundry producing sand castings in aluminium alloy for automotive engine components had a reject rate of 20% due to casting defects. A flux degassing unit was set up on a trial basis. The unit delivered powdered chloride/fluoride flux into the melt through a dip pipe using nitrogen carrier gas. The treatment floated out oxides contained in the melt, improving its fluidity and hence the reliability of the casting process. The reject rate was reduced to under 3%, and the melting, sand and labour costs per good casting produced were reduced by 14%.

On an order for 10 tonnes of a particular casting, energy costs were reduced by £450 and labour costs by £4500.
Rotary degassing systems
Rotary degassing uses a hollow ceramic or graphite tube and rotor wheel to fragment the emerging nitrogen gas bubbles and disperse them in the liquid metal (Fig 6). The process can reduce the hydrogen content of the melt to very low levels in a short time and is also effective in floating out large oxide films, thereby reducing the incidence of casting defects.

Drossing fluxes are applied to the surface of the melt to promote separation of entrained oxide dross from the molten metal, to leave a dry powder which is easily skimmed off. The molten fluxes also form a barrier layer to prevent hydrogen pick-up.

The fluxes had been supplied in powder form and were prone to entrainment in the furnace exhaust gases. These losses reduced the effectiveness of the flux and increased emissions of particulate and acid gases to atmosphere.

Foseco, a manufacturer and supplier of fluxes, reviewed the requirements for drossing fluxes. Fluorides were a major environmental concern, but could not be completely removed from formulations without rendering the fluxes ineffective. It was considered that the losses into the exhaust gases could be much reduced by supplying the flux in granular form, which would substantially reduce fluoride emissions without any change to the formulation of the fluxes.

Trials were carried out in a gas-fired bale-out furnace and in a reverberatory furnace, using exothermic and sodium-free drossing fluxes. It was found possible to reduce the addition rate to 0.125% when using a granular flux, 50% lower than with powder flux, demonstrating that the granular materials are utilised much more efficiently.

The results of the trials are given in Tables 2 and 3, and indicate that the use of granular fluxes results in substantially lower emission levels. The two types of granular flux yielded very similar emission concentration results for fluoride, the element of greatest environmental concern in foundry exhaust stack emissions.

<table>
<thead>
<tr>
<th></th>
<th>Emission concentrations with exothermic dossing flux (mg/m³)</th>
<th>Emission concentrations with sodium-free drossing flux (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Powder Granular</td>
<td>Powder Granular</td>
</tr>
<tr>
<td>Total particulate</td>
<td>0.85 0.6</td>
<td>1.1 0.6</td>
</tr>
<tr>
<td>Gaseous chloride</td>
<td>0.98 0.49</td>
<td>0.98 0.46</td>
</tr>
<tr>
<td>Total chloride</td>
<td>0.99 0.47</td>
<td>0.99 0.6</td>
</tr>
<tr>
<td>Fluoride</td>
<td>11.7 2.4</td>
<td>6.5 2.6</td>
</tr>
<tr>
<td>Sulphur oxides</td>
<td>12.6 1.76</td>
<td>7.4 0.77</td>
</tr>
</tbody>
</table>

Table 3  Emission concentrations in extracted gas from a reverberatory furnace

<table>
<thead>
<tr>
<th></th>
<th>Emission concentrations with exothermic dossing flux (mg/m³)</th>
<th>Emission concentrations with sodium-free dossing flux (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Powder Granular</td>
<td>Powder Granular</td>
</tr>
<tr>
<td>Total particulate</td>
<td>2.9 0.7</td>
<td>2.6 0.7</td>
</tr>
<tr>
<td>Gaseous chloride</td>
<td>0.93 0.36</td>
<td>1.24 0.26</td>
</tr>
<tr>
<td>Total chloride</td>
<td>0.82 0.72</td>
<td>0.98 0.32</td>
</tr>
<tr>
<td>Fluoride</td>
<td>13.7 3.53</td>
<td>10.2 3.74</td>
</tr>
<tr>
<td>Sulphur oxides</td>
<td>4.69 0.2</td>
<td>3.23 0.57</td>
</tr>
</tbody>
</table>
Rotary degassing units can generate a vortex at the surface of the melt, drawing air in and increasing oxidation rates. However, a baffle board extending a short distance below the melt surface will prove effective in preventing the formation of a vortex.

One recent development uses the flow of nitrogen to deliver powdered flux to the melt and, thereby, improve the efficiency of oxide removal, or to deliver treatment materials and alloy additions.

Where the alloy contains magnesium, using nitrogen for degassing may generate solid magnesium nitride particles. This may offer an advantage for some applications, in that a large number of nuclei are created on which the remaining hydrogen can precipitate. Any hydrogen porosity will be extremely fine and well dispersed, and will have little effect on the properties of the casting. For very demanding applications, however, it may be necessary to use argon gas for degassing to prevent the build-up of nitrides.

Note: Degassing removes desirable particles, such as grain refiners, in addition to unwanted oxides. For this reason the addition of grain refiners must always take place after degassing.

**Case study 3 - Rotary degassing improves a foundry’s yield by 5%**

A foundry, producing a range of diesel engine components in aluminium alloy weighing up to 200 kg, installed a rotary degassing unit. The unit comprised a ceramic rotating tube and impeller that could be immersed in the melt. Dry nitrogen purge gas was introduced through the rotating tube and dispersed into the melt as fine bubbles by the action of the impeller. This action caused hydrogen dissolved in the melt to come out of solution and enter the nitrogen bubbles, which then carried it to the surface.

The degassing unit reduced the hydrogen content to very low levels in around 10 minutes. The gas bubbles also floated out oxide films, with the resulting dross being skimmed from the melt surface.

Casting defects due to hydrogen porosity or poor fluidity of the melt have been virtually eliminated, thereby increasing the yield of sound castings by about 5%. For an annual output of 200 tonne/year, the foundry has reduced its energy costs by £2 500/year and its labour costs by around £30 000/year.
4.5.3 Copper base alloys

Because both hydrogen and oxygen are soluble in copper, steam is generated as the melt cools, leading to porosity defects in the solidified casting. Both gases need to be removed to control porosity and maximise the yield of good castings.

Porosity is typically controlled by an oxidation/deoxidation process:

- melting is carried out under oxidising conditions, sometimes using an oxidising flux to reduce the hydrogen level;
- oxygen is then removed prior to casting by the addition of a phosphorus-based deoxidiser, such as phosphor copper, although reactive metals such as aluminium are used with some alloys.

Additions of phosphorus need to be carefully controlled, as any excess will react at the melt surface with gases arising from the mould, potentially increasing porosity in the casting.

Aluminium bronzes are melted under oxidising conditions. Degasification with nitrogen may be required to remove hydrogen and oxygen. A fluoride flux is used to assist in the removal of aluminium and other oxides.

For some alloys, melting under reducing conditions is preferred, to minimise losses by oxidation. Reducing conditions in the melt are achieved by using a reducing flux or applying a cover of granulated charcoal to the surface. Where charcoal is used, it should be preheated before use, preferably to red heat, to expel any moisture that would otherwise dissociate and generate hydrogen which would be absorbed by the melt. The disadvantage with the reducing approach is that any hydrogen present is difficult to remove from the melt and the potential for gas porosity in the casting remains.

4.6 Avoidance of pigging

Molten metal in excess of that required for pouring the moulds must be pigged, reducing yield.

Avoid excessive pigging by ensuring that the quantity of metal melted is no greater than that necessary to ensure that all the moulds are filled reliably. A target of less than 5% of metal pigged is usually realistic.

Pigging is sometimes necessary for other reasons, such as a defective mould, unsatisfactory metal composition or low metal temperature. If the amount of metal pigged for such reasons is significant, review the foundry operation and take remedial action. In high volume operations it is usually possible to return metal to the furnace or treatment station, only pigging in the event of a prolonged delay on the moulding line.
Moulding and casting practice impacts on the production of good castings.

‘Box yield’ is calculated by dividing the weight of metal contained in the castings produced in the mould box by the weight of metal poured. Box yield will always be less than one, because the metal poured includes that required to fill the running and gating system and the feeders.

Box yield can be maximised by:

- ensuring good layout of the patterns and the running and gating system in the mould box;
- correctly dimensioning the running and gating system to ensure smooth filling, while avoiding oversizing;
- using ceramic foam filters to capture oxides and other non-metallic particles;
- correctly feeding, to compensate for shrinkage during cooling and solidification;
- using insulating or exothermic feeder sleeves to reduce the volume of metal in the feeders and save space in the moulding box.

This section looks at all these areas and outlines best practice in moulding and casting operations. Several case studies are included, which highlight the benefits that can result from using the best techniques.

### 5.1 Layout and patterns and running system

Foundries employing automated moulding lines operate with a small number of standard moulding box or pattern plate sizes. Jobbing or short run foundries are generally more flexible in this respect and will often make a box of the specific dimensions required to contain the sand mould for a particular casting.

Where the available moulding box size allows, box yield can be increased by carefully planning the layout of the running and gating system to increase in the number of castings per mould. Using insulating or exothermic feeder sleeves or exothermic inserts can increase the volume of metal available for feeding from just 14% of the feeder volume to 75% or more. Consequently, much smaller feeders can be used, saving box space and improving box yield. It is also possible to save space by feeding two or more castings, or in some cases sections of individual castings, from a single feeder.

‘Direct pouring’ units incorporating an insulating sleeve and ceramic filter can replace conventional pouring basins, sprues and feeders with a single unit, substantially reducing the space required for the running system and often eliminating the need for runners altogether on small castings.
5.2 Design of the running and gating system

The running and gating system should ensure smooth filling of the mould and the production of sound castings free of air bubble defects and slag, oxide or sand inclusions. The main components are shown in Fig 7.

Any turbulence at the metal surface will entrain air, increase oxidation and potentially erode the walls of the running system and mould.

Running and gating systems are often oversized, because of the use of excessive safety factors or ‘standard’ patterns, and this reduces box yield. If oversizing causes the system to not run full, air entrainment will occur, increasing oxidation and causing bubble and oxide inclusion defects in the casting.

Example - The benefits of increasing the number of castings per mould

A foundry realised it could increase the number of castings per mould from three to four, without having to increase the volumes of the running and gating system and the feeders. The castings each weighed 2 kg and were produced from a sand mould. Six kg of metal was required to fill the pouring basin and running and gating system.

\[
\text{Box yield (\%)} = \frac{\text{Weight of castings}}{\text{Total weight of metal poured}} \times 100
\]

For three castings per mould, the box yield was, therefore:

\[
\frac{3 \times 2}{(3 \times 2) + 6} \times 100 = 50\%
\]

With a fourth casting being produced from the mould without having to increase the volume of the running and gating system, the box yield would then increase to:

\[
\frac{4 \times 2}{(4 \times 2) + 6} \times 100 = 57.1\%
\]

In addition to reduced melting costs, the foundry also reduced requirements for moulding sand and binder chemicals. More saleable castings were produced without any increase in fixed costs and overheads, increasing profits.

5.2 Design of the running and gating system

The running and gating system should ensure smooth filling of the mould and the production of sound castings free of air bubble defects and slag, oxide or sand inclusions. The main components are shown in Fig 7.
A good running and gating system will:
- control the flow of metal to reduce or eliminate turbulence during pouring and filling ('turbulent-sensitive' metals);
- allow rapid filling ('turbulent-insensitive' metals);
- avoid mould or core erosion;
- prevent the ingress of slag into the mould cavity;
- avoid the entrainment of air into the flowing metal;
- make adequate provision for feeding the casting as the metal cools and changes volume;
- maximise the yield of good castings.

Keep moulding practices under review to ensure that running and gating systems are correctly sized and that available techniques to improve yield are used to maximum advantage.

5.2.1 The pouring basin

If possible, the pouring basin should be pear-shaped and incorporate a step so that the first metal poured does not immediately enter the sprue. The height should be sufficient to prevent the creation of a vortex, thereby preventing the entrainment of floating slag or dross and air as the metal enters the sprue.

On high volume moulding lines, space limitations often dictate the use of conical pouring cups positioned directly above the sprue. Automated pouring units are normally used, which retain any floating slag or dross. With this system, turbulence in the sprue is almost inevitable. To cast 'turbulent-sensitive' metals, such as ductile iron, a ceramic filter is provided in the running system to capture any resulting oxide films and eroded sand.

5.2.2 The sprue

A stream of molten metal accelerates as it falls and consequently its cross-sectional area decreases. The sprue should, therefore, be tapered downwards and should be dimensioned such that it runs full without turbulence or air entrainment.

For practical reasons, a parallel sprue is often used. In these cases, a rectangular cross-section with radiused corners is preferable, as these have less tendency to form a vortex. If a reverse taper has to be used, keep it short (<100 mm) and of rectangular cross-section. The base of the sprue should incorporate a sump or well, to decelerate the metal before it enters the runner, thereby reducing splashing and air entrainment and helping to ensure that the runner runs full. For 'turbulent-sensitive' metals, the well should be at the lowest point of the mould.

5.2.3 The runner bar

The runner bar distributes metal from the bottom of the sprue to the ingates through which metal enters the mould cavity. To minimise turbulence and air entrainment, avoid abrupt directional and sectional changes. Locate ingates on straight sections of the runner bar.

It is good practice to provide a runner bar extension or 'blind end' to receive the first metal poured. This metal is the coldest and most liable to contain entrained air and slag or dross inclusions.

Where there are two or more gates along a runner bar, the runner bar should be progressively reduced in section to maintain a reasonably uniform velocity and to promote equal flow through each gate and steady filling of the mould without recirculation effects. Changes in section should not be abrupt, rather a gentle taper at each gate. In the case of ductile iron, a continuous taper along the length of the runner is often preferred.
5.2.4 Ingates

Ingates should be dimensioned such that liquid metal flows smoothly into the mould cavity without splashing or turbulence, and yet fast enough to avoid lap defects or misruns.

If the casting has ‘legs’, or more than one low point, gate each one separately to avoid ‘waterfall’ effects as the casting fills.

Generally, ingates should be of rectangular cross-section and of a thickness that will not create a hot spot (with consequent shrinkage problems) at the junction with the casting.

For casting aluminium, gates should be taken off the top of the runner and enter the bottom edge of the casting.

5.2.5 Use and location of filters

Ceramic foam filters are used extensively in the casting of aluminium, ductile iron and some copper alloys to capture non-metallic inclusions and oxide films. Filters also have a smoothing effect on the flow, reducing turbulence downstream. They can be placed either in the running system close to the sprue, or close to the ingates. A slag pocket on the top of the runner immediately before the filter can allow large particles of slag to collect without blocking the filter. Other, more complex features, traditionally provided to trap slag and prevent it from entering the mould cavity, are not required.

For large castings the area of a single filter may not be adequate for the required mould filling rate. If there are a number of ingates, it may be appropriate to place a filter between the runner bar and each ingate. Alternatively, the running system can incorporate several parallel branches, each with a filter.

Ceramic filter material is of a much lower density than the metal. The remains of filters in the running system scrap readily float out during remelting and do not affect re-use of the metal.

**Case Study 4 - Using molten metal filters to reduce melting costs and reject levels**

Sandwell Castings is a large non-ferrous foundry producing castings for a variety of market sectors in gravity dies, greensand and carbon dioxide process-moulds. Most products are made in aluminium alloys, but yellow metals are also cast. Melting is carried out in coreless induction furnaces. Extensive use is made of ceramic foam filters in both die and sand castings.

Virtually all the castings are poured by hand, making it difficult to attain product consistency. However, the introduction of a foam filter in the running system has alleviated this problem, by trapping inclusions and restricting the flow of metal. The filter has cut scrap and reject levels by two-thirds, increasing yield and saving £1.72 on a casting weighing 2.42 kg when fettled (see Table 4). For an output of 200 tonne/year of finished castings, Sandwell has saved £140 000/year.

Use of filters has also reduced the incidence of inclusions resulting from turbulence or from mould or core breakdown.

**Table 4 Cost per good casting at Sandwell**

<table>
<thead>
<tr>
<th></th>
<th>Without filter (£)</th>
<th>With filter (£)</th>
<th>Saving (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting cost</td>
<td>1.37</td>
<td>0.84</td>
<td>0.53</td>
</tr>
<tr>
<td>Metal loss cost</td>
<td>0.48</td>
<td>0.29</td>
<td>0.19</td>
</tr>
<tr>
<td>Labour cost</td>
<td>3.92</td>
<td>2.41</td>
<td>1.51</td>
</tr>
<tr>
<td>Filter costs</td>
<td>-</td>
<td>0.51</td>
<td>(0.51)</td>
</tr>
<tr>
<td>Total/casting</td>
<td>5.77</td>
<td>4.05</td>
<td>1.72</td>
</tr>
</tbody>
</table>
5.2.6 Top pouring

Top pouring, using ‘direct pouring’ units, can be used for smaller castings in ‘turbulent-sensitive’ metals. A typical unit is shown in Fig 8. ‘Direct pouring’ units consist of an insulated feeder sleeve with a filter in the base, and are positioned directly above the mould cavity. Metal is poured directly into the feeder sleeve. Very high box yields can be achieved, as a conventional running system is not required. Satisfactory castings can be produced from mould depths up to about 90 - 100 mm by this method. At greater mould depths, casting defects can occur, due to air and dross entrainment by the falling metal stream.

Moulds for ‘turbulent-insensitive’ metals, such as grey iron, can be top poured to much greater depths, as slag and oxides are molten at pouring temperatures and, therefore, float out. The limiting factor is usually the potential for erosion of moulds and cores, beyond which conventional sprue and side gating must be provided.

5.3 Pouring and filling

5.3.1 Pouring temperature

Metals should be delivered to the mould at a temperature that will fill it without cold metal defects occurring and also ensure adequate feeding as the casting solidifies.

Unnecessarily high pouring temperatures increase shrinkage of the melt prior to solidification, increasing feeding requirements.

5.3.2 Introduction of defects during the casting of ‘turbulent-sensitive’ metals

The process of casting should minimise the potential to introduce defects, thereby maximising the yield of good castings.

If the casting is gravity poured, correctly-size the sprue and use uninterrupted pouring such that the sprue runs full while the mould is being filled. If air bubbles are entrained and pass into the mould cavity, a series of oxide trails and bubble defects will be created, running upwards through the casting from the ingates.

The metal should advance fast enough to avoid arrest of the liquid front, and yet smoothly enough to avoid turbulence. Any arrest of the liquid front allows an oxide layer to form; when flow recommences, the layer is overstepped and an ‘oxide lap’ will form. If the arrest is prolonged and allows solidification to take place, a ‘cold lap’ will form.

The mould must be filled continuously from the bottom, and the design of the casting or the orientation of the mould must be such that the liquid metal cannot fall or slide downwards.

Give special consideration to heavy sections and horizontal areas, to ensure that the advance of the liquid front is fast enough to avoid the possibility of lap defects. A particular problem occurs where the shape of the casting is such that two liquid fronts must join and form a confluence weld during filling of the mould. If one front is arrested, the oxide film will thicken and will not be displaced by contact with the second front. The resulting oxide film defect will extend right through the wall of the casting. Provided both fronts are moving, contact will be made when the oxide film is forming. The film will break, slide back and become folded against the mould wall by the flow of metal.
Horizontal areas are particularly prone to defects of this type because streams of metal tend to enter the horizontal area in a random manner, with many arrests of the liquid front which allow the oxide film to thicken (see Fig 9). The problem can sometimes be overcome by inclining the mould so that the area concerned is no longer horizontal and can fill smoothly from one edge.

**Fig 9 Oxide lap defects**

Steady filling interrupted while filling horizontal sections

Unstable filling of horizontal area

Potential for oxide laps corresponding to sides of rivulets

5.4 Feeding

5.4.1 The importance of correct feeding

The aim of feeding is to reduce solidification shrinkage and porosity, thereby maximising the yield of good castings. A feeder provides a casting with a supply of molten metal to compensate for shrinkage of molten metal during cooling and solidification and for dilation of the mould walls (where moulds are not rigid).

Short freezing range alloys tend to form large cavities and are easy to feed. Long freezing range alloys have a ‘mushy’ zone which is more difficult to feed, resulting in dispersed porosity. It is possible to improve feeding by positioning chills to create a steep temperature gradient and promote directional solidification towards the feeder.

Feeders can be ‘gated through’ or ‘dead’, depending on whether the metal flows through the feeder before entering the mould cavity or enters the feeder from the mould cavity. In the latter case, an additional ingate is sometimes provided directly into the feeder so that it receives hotter metal than would be the case if it was filled entirely through the mould cavity. Filling of a mould takes place quickly, but feeding is much slower.

There are a number of rules for successful feeding:

- the feeder MUST NOT solidify before the casting;
- the feeder must contain sufficient liquid metal to compensate for the contraction of the metal in the mould cavity;
- the junction between the feeder and the casting should not form a ‘hot-spot’ that remains liquid longer than the feeder;
- the feed path linking the feeder to the heavy section must not freeze before feeding of the heavy section is completed;
- there must be sufficient pressure differential between the feeder and the regions that require feeding to cause the liquid metal to flow;
- there must be sufficient pressure to suppress gas porosity.

5.4.2 When not to feed

Feeding is often unnecessary on small castings and may even be harmful in the case of thin-walled castings. If the feeder is not correctly placed, its filling may reduce the rate of filling the remainder of the casting, causing misruns or oxide lap defects. Shrinkage in thin walls (relative to their area) will pull in the ‘skin’ of the partially solidified casting, reducing the wall thickness in a uniform manner. Shrinkage can be allowed for in the dimensions of the pattern.

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Case study 5 - Reduction in poured weight using insulated feeder sleeves and filters

Barron-Clark Castings Ltd produces castings in aluminium alloys by the Alphaset resin bonded sand process.

Ceramic filters (sometimes incorporated in refractory feeder sleeves) are used on every Alphaset mould. They not only help to reduce the incidence of non-metallic inclusions in the castings, but also allow the quantity of sand used to be significantly reduced. For example, before the use of filters it was common to place runner bars on each side of 2 m long aluminium balustrade castings. Now, they are simply poured through filters on the top, significantly reducing the width of the long moulds and hence the amount of resin bonded sand required. In addition, the quality of the castings has been improved and the fettling requirements have reduced.

For automotive parts, a sump casting is poured directly through an insulating feeder sleeve with a filter in its vase. The benefits to Barron-Clark include:

- a reduction in poured weight from 11.5 kg without filter to 7.5 kg with a filter;
- a 3.5% reduction in scrap rate;
- a reduction in the requirements for moulding sand and binder.

These benefits have increased yield and realised direct cost savings of £3.62 on each 6.25 kg casting (see Table 5). For a typical annual production of 1 000 castings, the savings amount to £3 620. Additional, unquantified benefits result from less fettling, a higher production rate and less sand disposal, an increasingly important area with the higher rates of Landfill Tax.

<table>
<thead>
<tr>
<th></th>
<th>Without filter (£)</th>
<th>With filter (£)</th>
<th>Saving (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting cost</td>
<td>4.23</td>
<td>2.43</td>
<td>1.80</td>
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<td>Metal loss cost</td>
<td>1.58</td>
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<td>Labour cost</td>
<td>6.42</td>
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<tr>
<td>Filter costs</td>
<td>-</td>
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<td>(0.81)</td>
</tr>
<tr>
<td><strong>Total/casting</strong></td>
<td><strong>12.23</strong></td>
<td><strong>8.61</strong></td>
<td><strong>3.62</strong></td>
</tr>
</tbody>
</table>

5.4.2 When not to feed

Feeding is often unnecessary on small castings and may even be harmful in the case of thin-walled castings. If the feeder is not correctly placed, its filling may reduce the rate of filling the remainder of the casting, causing misruns or oxide lap defects. Shrinkage in thin walls (relative to their area) will pull in the ‘skin’ of the partially solidified casting, reducing the wall thickness in a uniform manner. Shrinkage can be allowed for in the dimensions of the pattern.
Because of the relative difficulty in feeding, castings to be produced in long freezing range alloys are usually designed with relatively thin walls that will accommodate shrinkage by reduction in thickness. The provision of feeders is then confined to any thicker sections and unavoidable ‘hot spots’ in the casting.

Where feeders are not used, moulds are prepared with a simple ‘flow off’ at the highest point and as far as possible from the ingates. This set up allows gas to escape easily, ensures that the mould is filled and carries off any floating slag or dross. Feeding requirements are met through the ingate or by means of the ‘flow off’.

5.4.3 Feeder efficiency

A feeder must have a high volume-to-surface ratio to ensure that it does not solidify completely before it has done its job. In theory, a sphere is the most efficient shape, but a vertical cylinder with hemispherical ends is better able to meet liquid head requirements and is usually more practical for moulding purposes.

Where the feeder is not open to the atmosphere, a notch is provided on the top of the feeder pattern to create a ‘hot spot’ in the mould and encourage the development of the shrinkage cavity.

The shrinkage cavity in a solidified feeder is in the form of a cone, with a volume around 14% of that of the feeder. This is illustrated in Fig 10. In practice, only about 10% of the volume of the feeder is used to supply the casting.

Correct sizing of a feeder is important:

- an undersized feeder will fail to prevent the occurrence of shrinkage defects;
- an oversized feeder will delay the solidification of the casting because of the increased heat input to the mould, and may increase gas porosity because more time is available for bubbles to nucleate and grow.

A conventional feeder is at the optimum size when its modulus is about 1.2 times that of the casting.

For a feeder to function correctly, the gating must freeze and isolate the feeder from the running system as soon as possible after completion of pouring. The shrinkage cavity in the feeder must be initiated before the solidifying surface of the feeder acquires sufficient strength to prevent collapse.

5.4.4 Feeding of cast irons

Cast irons expand during solidification, reducing feeding requirements. However, feeding may still be necessary to compensate for liquid contraction, particularly if the pouring temperature is unnecessarily high.

Ductile iron may require more feeding than grey iron because, depending on the metallurgy, it can contain a wide ‘mushy’ zone during solidification. This restricts flow and prevents expansion.
displacing the remaining liquid metal to areas requiring feeding. Instead, expansion forces cause the mould walls to dilate.

Conventional feeders sometimes prove unreliable on ductile iron castings. The solidifying surface may be strong enough to prevent the formation of an open shrinkage cavity. A vacuum is then formed within the feeder, which inhibits metal flow to the casting and may even cause a reversal of flow if pressure gradients are unfavourable.

5.4.5 Feeder sleeves

The correct application of feeder sleeves substantially improves the box yield and reduces melting costs.

The use of insulated feeder sleeves substantially reduces the rate of solidification of the feeder, and allows smaller feeders to be used without any reduction in feeding efficiency. Because solidification is delayed, much more of the volume of the feeder is available to feed the casting. Feeder sleeves are available in a range of sizes and in both open top and ‘blind’ form.

Exothermic sleeves and ‘hot top’ compounds (in which heat is generated by chemical reaction) can be used to delay solidification of the feeder still further and increase its effectiveness. The solidified surface of the feeder is almost flat, maximising feeder efficiency, as shown in Fig 11.

It is often not possible to locate conventional feeders adjacent to the sections where feeding is required. Instead, a heavy feed pad is needed on the casting, between the point of attachment of the feeder and the section to be fed (see top half of Fig 12). An insulating or exothermic feeder sleeve can sometimes substantially improve box yield, because its smaller diameter and separate placement allow greater freedom in positioning it, saving box space and perhaps eliminating the requirement for a feed pad (see bottom half of Fig 12). On some hollow castings, there may be an advantage in placing the feeder inside the casting, so long as sufficient access for ‘knock off’ is available, for example, on a wheel hub casting with a heavy central section forming a bearing seat, as shown in Fig 12.
Fig 12 Yield improvement and space saving with an insulating feeder system
5.5 Computer simulation and analysis

Computer simulation is generally only viable for high volume repetition foundries, where the cost of running the simulation can be justified by the potential cost savings from yield improvement over a long production run.

Preparation of the computer model can be time-consuming, incurring costs and increasing the lead time required to produce the casting. Smaller foundries have usually relied on experience and ‘rule of thumb’ methods. The yield of ‘right first time’ castings from such methods may not be the highest possible, but for short runs, will generally be more economic.

The present generation of computer simulation software accepts data input from 3D computer aided design (CAD) software, enabling components to be optimised for ease of casting at the
design stage. This avoids the need for subsequent modifications to the design because the foundry has encountered difficulties in producing a sound casting, perhaps because a heavy section proves difficult to feed satisfactorily.

Where computer simulation is used, a 3D data set will enable a foundry to proceed directly to the tasks of locating and sizing ingates and runners, and determining feeding requirements. Lead time will be saved by eliminating the time-consuming task of preparing the computer model from 2D information.
Defective castings and yield

Inevitably, a foundry will produce some reject castings. Many of these will be detected during inspections and returned for remelting, while others may only be detected during machining operations. In the latter event, an entire batch of castings may be rejected by the customer.

The overall effect of defective castings is to reduce yield significantly.

Failure to monitor defects and take appropriate remedial action can easily outweigh any potential benefits from more efficient running and feeding systems.

This section looks at some of the main causes of casting defects, and previous sections have also covered aspects of good practice that will help foundries to reduce the incidence of defects. However, there are many more causes of casting defects and it is beyond the scope of this Guide to offer comprehensive treatment of such a major subject. Sources of further reading are listed in Section 8.

6.1 Pattern makers’ contraction

The degree of constraint exerted by the mould affects the amount of contraction during cooling.

A simple-shaped casting not constrained by the mould or cores will shrink to the maximum extent, as predicted by the coefficient of expansion of the alloy from which it is cast.

A casting with large internal cores, or a casting from a box or other hollow shape, will be constrained by the mould or core and will be forced to deform plastically during cooling. The amount of plastic deformation will depend on the strength of the casting and the rigidity of the mould or core. The resulting shrinkage is not always easy to predict with the required level of accuracy. One way of overcoming this problem is to build the pattern with extra material on dimensionally important surfaces. Making and measuring a trial casting will determine the amount by which the pattern should be trimmed to give the required casting dimensions.

6.2 Air entrainment

Air entrained by turbulence in the running system creates bubbles, which rise through the mould and tend to get trapped on horizontal surfaces above the ingates. In ‘turbulent-sensitive’ metals where solid oxides are generated, oxide trails result, rising from the ingates. Larger bubbles escape from the liquid surface, but smaller ones have insufficient buoyancy to break the oxide films and remain just below the casting surface, as shown in Fig 15.
6.3 Core blows

When a sand core is heated by the metal poured into the mould, the resin binders break down and generate gas which then attempts to escape.

If the gas fails to escape via the core print, the gas pressure will build up to the point where a bubble is formed in the metal and floats upwards, becoming trapped under the solidified upper surface of the casting as shown in Fig 16. Bubbles of core gas can be very large.

The problem can be overcome by ensuring that the cores are adequately vented and that the mould is filled before extensive breakdown of the binder occurs. Provided that the hydrostatic pressure of the liquid metal is greater than the pressure of gas in the core, this will suppress the formation of bubbles of core gas.
6.4 Lustrous carbon defects

If the atmosphere within the mould is rich in hydrocarbons, their decomposition can deposit a carbon film on the advancing melt surface. Any turbulence will then generate surface lap defects similar to those arising from oxide films. On cast irons these defects have the appearance of elephant skin.

Lustrous carbon defects tend to be associated with resin binder systems, where a high proportion of mechanically-reclaimed sand is used. Resin remaining on the sand grains increases the level of organic compounds in the moulding sand. Lustrous carbon defects on cast iron can also occur in the lost foam process, where decomposition of the polystyrene foam creates a mould atmosphere very rich in hydrocarbons.
A number of new technologies offer advantages in terms of yield, dimensional accuracy, ease of production of complex geometries, and improved foundry sand recycling rates. This section looks at some commercially-proven examples.

### 7.1 Lost foam casting

The lost foam process uses expanded polystyrene patterns and dry unbonded sand.

The main benefits of the process are:

- it has the ability to produce complex geometries and internal passages;
- lower cost mould preparation as separate cores are not required;
- almost all sand is re-usable, as no binders are used;
- high dimensional accuracy can reduce machining allowances or eliminate the need for machining.

The disadvantages of the process are:

- the high capital cost of moulding machines and dies to produce the patterns;
- it is unsuitable for certain alloys, where carbon pickup from the decomposition of styrene vapour will lead to the carbon content of the metal exceeding specification limits;
- there is the potential for surface film and oxide film defects, such as lap and confluence defects, to develop;
- it has certain size and geometrical limitations.

Lost foam casting is best suited to the production of complex geometries in long production runs, for example, aluminium engine cylinder blocks and heads, and ductile iron valves and pipe fittings. In certain cases, lost foam casting enables a component to be produced as a single casting, whereas with conventional processes it would have to be made as a bolted assembly of simpler castings.

The expanded polystyrene pre-forms are produced in aluminium dies. A pattern can be assembled from a number of pre-forms glued together, to create internal passages and other complex geometries. The assembled pattern is coated with ceramic to prevent molten metal penetrating or eroding the sand. Dry sand is compacted into and around the pattern, making sure that the internal core spaces are filled. As liquid metal enters the mould, the foam pattern is vaporised and replaced by the metal. The ceramic coating on the pattern must be sufficiently porous to allow the styrene vapour to escape into the sand. Decomposition products from the foam can cause surface or internal defects in the casting if they are unable to escape into the mould sand.

Molten aluminium can be slow to advance through the foam, advancing progressively from the ingates rather than upwards from the lowest point of the mould as it would in a conventional sand casting process. If filling is too slow, the oxide film on the advancing front has time to thicken, increasing the risk of confluence or lap defects.
7.2 Vacuum moulding

The vacuum moulding process enables moulds to be made of dry, unbonded sand. As no binders are used, almost all sand is reusable.

To prepare the mould, plastic film is placed over the pattern. When a vacuum is drawn through vent holes in the pattern, the plastic film conforms exactly to the pattern. One half of the moulding box is then filled with sand and a vacuum applied to the sand from a separate vacuum chamber. The vacuum is then released from the pattern, which is separated from the mould. The vacuum applied to the sand retains it in a shape corresponding to the pattern. The two halves of the moulding box are assembled and the mould is poured while the vacuum is kept on. As the vacuum extracts the breakdown products of the plastic film and there are no binders to generate gases, the potential for gas porosity defects is minimised.

The process is not suitable for high volume production, but does offer good dimensional accuracy and finish.

7.3 Bottom filling

A number of processes have been developed to permit moulds for aluminium castings to be filled from below, without turbulence. These set-ups eliminate the conventional pouring basin and downsprue, thereby reducing the volume of metal poured and increasing the yield. The moulding sand requirements for each mould are also reduced.

Methods of filling the mould include:

- counter gravity, by applying a vacuum to the mould (Hitchiner);
- inert gas pressurisation;
- electromagnetic metal pumping (Cosworth).

High production rates require a means of sealing the mould to retain molten metal and allow disconnection from the pouring station. This can be achieved by:

- freezing off a neck or ingate at the entry to the mould cavity, by chilling or forced cooling (Hitchiner);
- rollover to invert the mould (Cosworth Process);
- ‘locking core’ sealing devices (Disamatic).
8.1 Help from Envirowise

If you require further advice or have any specific questions about taking action to improve foundry yield, the Environment and Energy Helpline on 0800 585794 can put you in touch with relevant technical experts. The Helpline can also:

- provide free, up-to-date advice on environmental issues;
- tell you about relevant environmental and other legislation that could affect your business;
- send you copies of relevant Envirowise publications;
- suggest other sources of information;
- arrange for a confidential, on-site waste review (known as a FastTrack visit) from an environmental expert to help you identify opportunities for resource efficiency and thus reduce costs.

Particularly relevant Envirowise Guides include:

- GG43 Environmental management systems in foundries
- GG104 Cost-effective management of chemical binders in foundries
- GG119 Optimising sand use in foundries

A wide range of case studies is also available, covering various sectors. All Envirowise publications are available free of charge through the Environment and Energy Helpline on 0800 585794 or via the Envirowise website (www.envirowise.gov.uk).

The website also carries other useful information, for example, on waste minimisation clubs and forthcoming events.

The Environment Agency general enquiries line (0845 9333 111) and website (www.environment-agency.gov.uk) can also provide advice and information on solvent management issues and legislative compliance.

8.2 Further reading

Many text books have been written that contain useful information on ways to improve the yield of foundries.

Particularly relevant books include:

- J Campbell
  Castings
  Butterworth-Heinemann 2003

- P Beeley
  Foundry Technology
  Butterworth-Heinemann 2001

The Institute of Cast Metals Engineers also publishes a range of handbooks and reference guides covering all aspects of foundry operations and technology.
Envirowise - Practical Environmental Advice for Business - is a Government programme that offers free, independent and practical advice to UK businesses to reduce waste at source and increase profits. It is managed by Momenta, an operating division of AEA Technology plc, and Technology Transfer and Innovation Ltd.

Envirowise offers a range of free services including:

- Free advice from Envirowise experts through the Environment and Energy Helpline.
- A variety of publications that provide up-to-date information on waste minimisation issues, methods and successes.
- Free, on-site waste reviews from Envirowise advisors, called FastTrack visits, that help businesses identify and realise savings.
- Guidance on waste minimisation clubs across the UK that provide a chance for local companies to meet regularly and share best practices in waste minimisation.
- Best practice seminars and practical workshops that offer an ideal way to examine waste minimisation issues and discuss opportunities and methodologies.