CHEMICALLY BONDED SAND: USE AND RECLAMATION
This Environmental Performance Guide discusses the use and reclamation of chemically bonded sand within the UK foundry industry. It examines in detail the cost of sand use, reclamation and disposal across the four main alloy sectors where sand is used for moulding and coremaking:  
- iron;  
- steel;  
- aluminium;  
- copper.

Until recently, UK foundries did not consider waste sand disposal to be a major problem; the sand was either disposed of on-site or to local landfill sites. To give some idea of the scale of the problem, the current cost to the UK foundry industry for over one million tonnes (t) of new sand used every year, and its subsequent disposal, is about £32 million.

The amount of sand purchased per tonne of casting produced in the four alloy sectors of the foundry industry is shown in Fig 1. Fig 2 shows sand purchase costs. The sectors, and individual foundries within each sector, have different production requirements. These production requirements mean that some foundries will need to use more sand than others. However, despite these factors, the figures overleaf show that there is scope for overall improvement in sand use within all alloy sectors.

Sand for foundry use is a finite resource that must possess certain chemical and physical characteristics. As stocks deplete, sand will become more difficult to obtain and therefore more costly to buy. Already, the post-quarrying costs of improving the mineral to meet the acceptance criterion of foundries has meant that raw material costs have risen. The high investment costs required to extract the sand has also led to some quarries being closed without all of the raw material being extracted. Sand is now often transported from further afield, which increases delivery costs. The constraints being placed on sand excavation operations - eg post-closure landscaping requirements - have also added to the problem of increasing costs for quarry operators.

Similar factors affect disposal costs. There are now fewer licensed landfill sites available for the disposal of controlled wastes. Therefore, waste sand has to be carried greater distances for disposal, resulting in increased transportation costs. Moreover, tighter legislative control of wastes and waste disposal sites has led to a rapid escalation in disposal costs. The landfill tax will also increase the cost of waste disposal to landfill.

Foundries now appreciate that these cost trends are irreversible. Better sand management techniques need to be developed and implemented to combat rising costs. In particular, foundries that use sand only once could achieve significant cost savings through sand reclamation.

The foundry industry produces a wide range of castings using many different processes. This diversity, coupled with the variation in size and number of castings produced by foundries, has hitherto made it difficult for an individual foundry to establish its performance relative to other foundries in its particular sector.
Nevertheless, by using Figs 1 and 2, the information given in this Guide and the sand action plan in Section 9, foundries can now improve an important aspect of their environmental performance and obtain cost benefits by implementing better management of sand and other raw materials.
2.1 SURVEY METHODOLOGY

The foundry industry information presented in this Guide was collected by means of a confidential postal survey conducted by Castings Technology International (Cti) on behalf of the Environmental Technology Best Practice Programme (ETBPP). A mailing list of 450 foundries that perform sand casting was constructed from lists of companies held by the ETBPP and Cti, and from the 1994 Foundry Yearbook. Each foundry on the list was contacted by telephone to establish if it used chemically bonded sand or greensand for moulding. Of the foundries using chemically bonded sands, 59% also use greensand for moulding. These foundries were also included in a separate survey of foundries using greensand. The use and reclamation of greensand in UK foundries is discussed in a separate Environmental Performance Guide.

Questionnaires were then sent to a final list of 380 representative foundries that use chemically bonded sand. These foundries were classified according to the main alloy type produced. Owing to the relatively small number of foundries producing specialist alloys, all data pertaining to the production of nickel and cobalt alloys were combined with that for steel. Production of magnesium alloys was combined with that for aluminium, and other non-ferrous alloys were combined with copper. This classification was also used for the data analysis.

The distribution of the 380 foundries between the four alloy sectors is shown in Fig 3.

2.2 RESPONSE PROFILE

Table 1 shows that the response rate to the survey was spread equally across all four alloy sectors.

<table>
<thead>
<tr>
<th>Foundry type</th>
<th>Number of foundries</th>
<th>Number of respondents</th>
<th>Percentage respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>195</td>
<td>52</td>
<td>27%</td>
</tr>
<tr>
<td>Steel</td>
<td>48</td>
<td>15</td>
<td>31%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>79</td>
<td>22</td>
<td>28%</td>
</tr>
<tr>
<td>Copper</td>
<td>58</td>
<td>16</td>
<td>28%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>380</td>
<td>105</td>
<td>28%</td>
</tr>
</tbody>
</table>

Table 1 Survey response by foundry type
The returned questionnaires also reflected the size distribution of the UK foundry industry, with its high proportion of small and medium-sized businesses (see Table 2).

The response profile can be examined further by comparing the average quantity of sand purchased annually with an estimate of the industry average. The amount of silica sand consumed annually by the foundry industry is estimated to be about 1.1 million tonnes. The total number of sand moulding foundries in the UK is estimated to be about 450. Allowing for about 34 000 t of sand used by the gravity die-casting sector (excluded from this survey), the average annual amount purchased by a sand moulding foundry is estimated to be 2 400 t. In comparison, the average quantity of sand purchased annually by the foundries that replied to the survey is 2 000 t. This implies that there were more replies from small foundries than from large ones.

Survey data were obtained from 28% of the foundries approached. The response profile also appears to be a fairly good reflection of the industry. It is therefore considered reasonable to extrapolate the results from the survey to the UK foundry industry as a whole.

<table>
<thead>
<tr>
<th>No of employees</th>
<th>No of respondents*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 9</td>
<td>13</td>
</tr>
<tr>
<td>10 - 19</td>
<td>21</td>
</tr>
<tr>
<td>20 - 49</td>
<td>38</td>
</tr>
<tr>
<td>50 - 99</td>
<td>15</td>
</tr>
<tr>
<td>100 - 199</td>
<td>6</td>
</tr>
<tr>
<td>&gt;199</td>
<td>1</td>
</tr>
</tbody>
</table>

*Not all respondents supplied size data

Table 2  Size of survey respondents
One variable in operating practice that affects sand costs is the type of sand used.

### 3.1 SAND CHARACTERISTICS

The characteristics of the four main types of sand used in UK foundries are summarised in Table 3.

<table>
<thead>
<tr>
<th>Sand type</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica</td>
<td>Cheap and versatile. Predominant sand product used by the industry.</td>
</tr>
<tr>
<td>Chromite</td>
<td>More refractory than silica. Thermally stable with greater chilling power. Provides a better surface finish on large castings. Mainly used for the production of large castings, and in areas of the mould where chilling is required.</td>
</tr>
<tr>
<td>Zircon</td>
<td>Similar to chromite, but produces a better finish as a finer grade is used.</td>
</tr>
<tr>
<td>Resin-shell</td>
<td>Actually refers to a binder system. The product as sold consists of either silica or zircon sand pre-coated with the resin. Commonly used for the production of moulds and cores to a high dimensional accuracy. Is easily removed from internal cavities and produces a good surface finish.</td>
</tr>
</tbody>
</table>

### 3.2 SAND USE BY SECTOR

Fig 4 shows the numbers of foundries in the four alloy sectors using each sand type.

### 3.3 SAND PRICES

The purchase price of sand has four components - extraction, preparation, packaging and transportation. The average purchase price per tonne is given in Table 4 (the silica and resin-shell data include information from the greensand survey). Appendix 1 shows the range of prices paid by foundries for sand products.

<table>
<thead>
<tr>
<th>Sand type</th>
<th>Average price per tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica</td>
<td>£20.40</td>
</tr>
<tr>
<td>Chromite</td>
<td>£165.00</td>
</tr>
<tr>
<td>Zircon</td>
<td>£259.00</td>
</tr>
<tr>
<td>Resin-shell (silica)</td>
<td>£136.00</td>
</tr>
</tbody>
</table>

### Table 3 Sand characteristics

### Table 4 Average sand prices

![Fig 4 Sand types used by foundries](image-url)
The degree to which sand reclamation is used within a foundry is another factor that influences operating costs.

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.

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.

4.1 SAND RECLAMATION TECHNIQUES

Early mechanical attrition equipment was typically based on conventional mineral crushing plant. Nowadays, this technique is being superseded owing to its high operating costs. Primary reclamation can be carried out using shot blast, drum or more commonly, vibration equipment. Secondary reclamation can be accomplished using more aggressive mechanical attrition techniques, wet scrubbing, or by thermal treatment.

4.1.1 Primary reclamation techniques

**Shot blast**

The mould and casting is loaded directly into the shot blast machine. The action of the shot blast results in complete disintegration of the mould and also cleans the surface of the casting. The sand and shot are subsequently separated.

**Drum**

Sand from the knock-out operation is loaded into a rotating drum fitted with both lifting and travelling bars. As the sand travels along the drum, the rotating and lifting action causes the sand particles to grind against each other and break down to individual grains. The sand grains fall through screens at the end of the drum, while oversize and tramp materials are removed for landfill disposal.

**Vibration**

Vibratory grid or screen equipment is the most widely used technique for primary reclamation purposes. The sieved sand is removed for subsequent treatment - eg cooling, size classification, thermal reclamation - and the residual material is collected for disposal.
4.1.2 Secondary reclamation techniques

Although proven secondary reclamation technologies are available, they are not widely used within the UK foundry industry, partly because of the relatively high capital costs of the equipment. As the costs of sand purchase and disposal increase, more foundries will consider secondary reclamation to be a cost-effective technology.

Pneumatic

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 binder resin 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.

Hammer mill

This technique has been used occasionally to reclaim silicate-bonded sands. Pre-dried silicate bonded sand is processed using a hammer mill. The mill has a number of hammer heads, which are mounted on a rotating shaft, to crush the particulated sand against the casing to remove the binder.

Centrifugal

Particulated sand is fed into a rotating drum where the centrifugal force throws it against a vaned ring. As further sand enters the unit, this too is forced against the drum wall and the frictional force between the sand grains removes the binder residues.

Wet scrubbing

In this process, water is added to the particulated sand to form a slurry. A mixing and scrubbing action is then used to produce grain-on-grain abrasion to remove the binder. Classification is normally undertaken prior to drying the slurry.

Thermal reclamation

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. Further details on thermal reclamation can be found in ETBPP publication GC3 entitled ‘Sand costs reduced by thermal reclamation’.

4.2 COST OF PRIMARY RECLAMATION

The cost of primary reclamation comprises capital expenditure on equipment and operating costs. About half the survey respondents with primary reclamation equipment provided data on capital costs, with slightly fewer supplying estimates of labour and maintenance, and about 25% providing energy costs.

4.2.1 Capital costs of primary reclamation

Capital costs of primary reclamation are compared, in Fig 5, with the amount of sand reclaimed annually by each foundry. Fig 6 compares the capital costs for different rated capacities in tonnes per hour.

Both Figs 5 and 6 demonstrate the wide variation in capital costs revealed by the survey. These costs depend on the type of equipment and whether it was purchased new or second-hand. The figures indicate that the average capital cost per tonne of sand throughput per hour is around £8 000.
Assuming that a foundry aims to recoup the equipment purchase cost within the first year, summation of all capital expenditure, compared with the total amount of sand reclaimed annually, gives an average capital cost of £11.40/t of particulated sand.

### 4.2.2 Operating costs

The operating costs associated with primary reclamation equipment include energy, labour and maintenance costs. The average values recorded by the survey are summarised in Table 5.

<table>
<thead>
<tr>
<th></th>
<th>Cost per tonne of primary reclaimed sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>£0.98</td>
</tr>
<tr>
<td>Labour</td>
<td>£2.80</td>
</tr>
<tr>
<td>Maintenance</td>
<td>£1.07</td>
</tr>
<tr>
<td>Total</td>
<td>£4.85</td>
</tr>
</tbody>
</table>

Table 5 Average operating costs for primary reclamation equipment

Emissions monitoring for particulates is now mandatory for all foundries. Where hot sand is processed, VOCs should also be monitored. Particulate emissions monitoring typically costs between £300 and £500, while simultaneous VOC emissions monitoring may cost an additional £200 - £300.

### 4.3 COST BENEFITS OF PRIMARY RECLAMATION

The potential cost benefits of primary reclamation for a foundry that does not currently reclaim its sand are summarised in Table 6.

### 4.4 RECLAMATION OF SAND IN UK FOUNDRIES

About 52% of the foundries that responded to this survey reclaim a proportion of used sand using a variety of particulation techniques; a few foundries also use secondary reclamation techniques. The remainder of foundries do not reclaim any sand.

The survey showed that 71% of iron foundries reclaim a proportion of used sand, compared with 40% of steel foundries and only 13% of copper foundries (see Fig 7). Aluminium foundries use proportionately more sand than other foundries, but only 27% use reclamation.
The cost benefits of reclaiming foundry sand are demonstrated in Fig 8 which shows the total sand costs per tonne of finished casting for different sand-to-liquid metal ratios with and without primary reclamation. The costs include new sand purchases, reclamation costs and sand disposal. In many cases, foundries using reclaimed sand are able to reduce total sand costs by more than 50%. Fig 8 also highlights the direct cost benefits of using a lower sand-to-liquid metal ratio.

4.4.1 Potential for sand reclamation in the UK

The 28% of UK foundries using chemically bonded sand that replied to this survey produce about 430 000 t of mixed sand annually. Given the representative nature of the response (see Section 2), it is reasonable to assume that the total amount of sand mixed annually by chemically bonded sand foundries in the UK is about 1.6 million t. The survey data indicate that about 40% of foundry sand is not being reclaimed and so the potential for reclamation in the UK is about 600 000 t. This represents a potential annual saving to the foundry industry of £15 million.

4.5 USE OF PARTICULATED SAND IN SAND MIXES

Particulated sand must be mixed with a proportion of new sand to produce a sand mix of sufficient quality for moulding or coremaking. New sand is added to ensure that the sand mix, when recoated with binder, has an adequate bench life and sufficient mould strength. Enough new sand is added so that the mixed sand is deemed ‘fit for purpose’.

The proportions of new sand used by survey respondents for moulding and unit sand mixes are shown in Fig 9. For the purposes of this Guide, unit sand is defined as that sand which is used for both moulds and cores. Fig 9 shows a considerable variation in the proportion of new sand used, reflecting the different production methods favoured by different foundries.

Fig 10 compares the percentage of new sand additions with the total amount of sand mixed annually. It shows that reclamation is by no means confined to the larger sand users. Many small foundries are using primary reclamation techniques to process fewer than 1 000 t of mixed sand annually.
In contrast, some foundries that do not use sand reclamation are purchasing up to 6,000 t of new sand annually.

In foundries that use reclamation techniques, the proportion of new sand added to mixes of moulding and unit sand varied by up to 75%, with an average addition rate of 25%. These figures suggest that, even in those foundries already reclaiming used sand, there is scope to further reduce new sand purchases.

Of the foundries that reclaim used sand, over 80% do not use any of it to make cores, preferring instead to use new sand only (Table 7). This suggests there is scope for using reclaimed sand in coremaking.

<table>
<thead>
<tr>
<th>New sand addition</th>
<th>% of foundries</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 10%</td>
<td>0</td>
</tr>
<tr>
<td>11 - 25%</td>
<td>10</td>
</tr>
<tr>
<td>26 - 50%</td>
<td>6</td>
</tr>
<tr>
<td>51 - 90%</td>
<td>2</td>
</tr>
<tr>
<td>100%</td>
<td>82</td>
</tr>
</tbody>
</table>

Table 7  Proportion of new sand in core sand mixes
Sand-to-liquid metal ratios are a further 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-to-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. These factors explain some of the differences in sand-to-liquid metal ratios observed in the four alloy sectors (see Fig 11).

Fig 11 Total mixed sand-to-liquid metal ratios in UK foundries
5.1 REASONS FOR OPTIMISING MIXED SAND CONSUMPTION

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:

- Increased productivity;
- 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.

Examination of the survey data and comparison between industry sectors suggests that the sand-to-liquid metal ratios shown in Table 8 should be suitable for most types of production.

Any foundry operating with a sand-to-liquid metal ratio in excess of those listed in Table 8 should review its production methods because there may be scope to reduce sand consumption.

<table>
<thead>
<tr>
<th>Alloy sector</th>
<th>Sand-to-liquid metal ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>up to 4:1</td>
</tr>
<tr>
<td>Steel</td>
<td>up to 5:1</td>
</tr>
<tr>
<td>Copper</td>
<td>up to 4:1</td>
</tr>
<tr>
<td>Aluminium</td>
<td>up to 12:1</td>
</tr>
</tbody>
</table>

Table 8: Typical sand-to-liquid metal ratios
6.1 BINDER TYPES

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 (see Table 9).

<table>
<thead>
<tr>
<th>Binder group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkaline-phenolic</td>
<td>An alkaline phenol formaldehyde resin, available in self-set or gassed variations.</td>
</tr>
<tr>
<td>Furane</td>
<td>A resin of urea formaldehyde and/or phenol formaldehyde and furfuryl alcohol, which is self-set with acids.</td>
</tr>
<tr>
<td>Phenolic-urethane</td>
<td>A phenol formaldehyde and isocyanate resin, available in self-set or gassed variations.</td>
</tr>
<tr>
<td>Resin-shell sand</td>
<td>Normally packaged as a sand pre-coated with phenol formaldehyde novalak resin, and set by heating.</td>
</tr>
<tr>
<td>Silicate</td>
<td>An inorganic system, self-set using esters or gassed with carbon dioxide.</td>
</tr>
</tbody>
</table>

Table 9 Binder groups

6.2 NUMBER OF BINDER SYSTEMS USED

The survey revealed that many foundries are using several binder systems (see Fig 12). A small percentage of respondents do not use any cores (a specialised production system), while the majority use one or two binder systems for moulding and coremaking. Two or three binder systems will generally provide a foundry with the required degree of flexibility. It is recommended that a foundry carries out a review of its binder requirements if it uses four or more binder systems.

The use of multiple binder systems has several disadvantages:

- there are extra training requirements;
- the potential effectiveness of sand reclamation is limited;
- stock maintenance for each binder system ties up capital;
- premium prices are often paid for smaller quantities;
- extra documentation is required to comply with the quality assurance standards.

The use of binders for moulding and coremaking in the four alloy sectors is discussed in Appendix 2.
6.3 BINDER COSTS

Although the survey was not designed to gather detailed information on binder costs, some general conclusions have been drawn.

The purchase costs of some binder materials varied widely between different foundries. For example, the purchase price of sodium silicate varied between £80/t and £1 000/t, with an average of £390/t. While some foundries have reduced packaging and transport costs by purchasing larger quantities of binder, other foundries have apparently also negotiated considerable discounts for bulk orders.

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 Table 10.

In many cases, the quantities of binder purchased, compared with the amounts of sand mixed, suggest that foundries are using addition rates up to four times higher than those considered ‘suitable’. Although excess binder is usually added to provide an adequate safety margin, better control of binder additions could reduce this considerably. 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:
- produce significant cost savings;
- reduce environmental emissions;
- improve sand reclaimability;
- reduced scrap and casting repair.

Users of gas-hardened systems also reported a considerable variation in gas use per tonne of binder. For carbon dioxide (CO₂)-silicate systems, 0.25 t of CO₂ per tonne of binder should be adequate for most production purposes. In contrast, the survey results showed that purchased amounts varied from 0.1 - 2.9 t of CO₂ per tonne of binder with, on average, one tonne of CO₂ purchased per tonne of binder. Although CO₂ is relatively cheap, optimising its use could produce significant cost savings.

Methyl-formate and amine gases used in organic gas-hardened systems are considerably more expensive. Moreover, VOC emissions to the atmosphere are a major environmental concern. Even with these more expensive materials, the amounts of gas purchased per tonne of binder were found to vary by a factor of ten. The figures indicate that excessive amounts of gas are wasted at considerable expense to the foundry.

Gas consumption can be reduced by:
- improved 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.
Metal yield is the ratio of the amount of metal melted to the weight of the finished castings. Five main factors affect metal yield:

- quality requirement;
- choice of mould-box size;
- the extent of runner and feeder systems;
- metal shrinkage;
- scrap casting rate.

Metal yield does not have a direct effect on sand use. However, an increase in yield may result in fewer moulds being produced, which means that less sand is used.

Lower metal yields are generally associated with higher integrity products where superior quality standards may be required, necessitating a more extensive feeding system. Lower yields, however, may also be indicative of higher scrap rates and excessive feeding systems. In these circumstances foundries should review process control and mould production methods.

The average metal yields for the four alloy sectors are given in Table 11.

A significant number of survey respondents declined to supply yield data. However, some general comments on yield can be made:

- The range of yields reported for grey iron and SG iron was from 40% to over 90%.
- Metal yields reported from steel foundries were more closely distributed; over 50% of respondents reported yields of between 50% and 60%. The lower average yield is mainly due to steel's shrinkage characteristics.
- Metal yields reported by aluminium foundries were fairly evenly distributed between 40% to over 90%.
- Many copper foundries appear to be achieving yields of between 50% and 70%, with a significant number achieving over 90%.

### Table 11 Average metal yields in the four alloy sectors

<table>
<thead>
<tr>
<th>Sector</th>
<th>Average metal yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron: grey</td>
<td>69%</td>
</tr>
<tr>
<td>spheroidal graphite (SG)</td>
<td>64%</td>
</tr>
<tr>
<td>Steel</td>
<td>51%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>71%</td>
</tr>
<tr>
<td>Copper</td>
<td>63%</td>
</tr>
</tbody>
</table>

METAL YIELD
Waste sand management is becoming increasingly important to foundries because the cost of disposal to landfill has increased dramatically in recent years. This is primarily due to tighter legislative control of both waste sand disposal and waste disposal sites. Moreover, the landfill tax will further increase disposal charges.

Survey respondents reported waste sand disposal costs ranging from ‘zero’, where disposal is carried out at the foundry’s own site, to over £20/t (see Fig 13); the average was £9.10/t. A similar cost distribution was obtained for the greensand survey and so the data from the two surveys were combined to produce Fig 13. Over 50% of foundries reported waste sand disposal costs of between £5 and £10/t.

Foundries reporting ‘zero’ waste sand disposal costs may not fully appreciate the effects of recent environmental legislation; these foundries are urged to contact their local Waste Regulation Authority (WRA) or the ETBPP’s Environmental Helpline on 0800 585794 for free advice. The new waste management licensing regime and other legislative changes have significantly increased the costs associated with the management of waste disposal sites. Moreover, the true cost of on-site waste disposal is often hidden, and not apparent to the foundry producing the waste.

As the spread in waste disposal costs was wider than expected, the data supplied by foundries were studied further to see if any one factor was critical. This showed that disposal costs for foundries close to landfill sites were similar to those for foundries where the sand is transported long distances. Some variation in the average disposal costs within different regions was found (see Table 12), but this was insufficient to account for the spread in costs noted in Fig 13.

Foundries are under ever-increasing economic pressure to reduce the amount of waste sand that is sent for disposal. Many foundries are starting to implement waste sand reduction strategies. However, foundries should consider developing a strategy to minimise waste from all processes.
When developing a sand action plan, three basic areas should be considered:

- sand purchase costs;
- sand use;
- used sand disposal/reclamation.

### 9.1 SAND PURCHASE COSTS

The cost of sand is governed mainly by the way in which the sand is packaged and transported to the foundry. Delivered sand costs may be halved by changing from bagged to bulk tanker deliveries. Even small foundries could benefit from installing a hopper to enable deliveries of new sand to be made by tanker.

Despite the relatively small quantities of binders used in chemically bonded sand mixes, annual binder material costs in foundries are often over £100 000. It is therefore important that the binders are used in the most cost-effective manner. Minimum additions produce direct savings, while good binder level control can yield significant indirect savings. Avoiding excessive binder addition will reduce the likelihood of gas defects, hot tearing and casting distortion. Eliminating insufficient additions will reduce the risk of mould collapse, inclusions, poor surface finish and dimensional inaccuracy.

Introducing a regular calibration regime at the sand mixer is often beneficial. However, variations in ambient temperature (even over a single shift period) and other variables such as pump wear, blockages and differences in the level of storage vessels should not be ignored.

Where gassed systems are used, gas costs are a significant element. It is therefore important to minimise gas use while maintaining satisfactory technical performance.

A significant number of foundries use multiple moulding and coremaking systems with their associated costs and control problems. A review of the need for such arrangements should be undertaken, particularly from the point of view of sand reclaimability.

In those foundries that use a single sand mix for production of the complete mould, it may be appropriate to consider the introduction of a facing/backing sand approach. In a facing/backing system, the backing sand mix has lower binder levels and therefore costs less than the facing sand mix.
9.2 SAND USE

Cost savings can be achieved by a reduction in sand use per tonne of castings produced. Every effort should therefore be made to reduce sand-to-liquid metal ratios. As several of the measures suggested in the action list below will reduce mould strength, it is important to evaluate fully any proposed changes prior to their implementation.

## ACTIONS TO REDUCE SAND COSTS

- Review purchasing contracts for sand and binders.
- Review delivery/transport arrangements.
- For sand mixes, introduce:
  - a regular calibration regime, or preferably, positive monitoring and control over binder system component delivery.
  - lockable controls to prevent unauthorised adjustment.
- Rationalise on binder systems wherever possible.
- For gas-cured systems:
  - introduce gas flow rate and use controls.
  - ensure gas tightness of equipment.
- Consider facing/backing sand arrangements.

## ACTIONS TO REDUCE SAND USE

- Ensure that mixer types/capacities equate with mixed sand demand.
- Train operators to keep strike-off sand to a minimum.
- Minimise sand-to-liquid metal ratios by:
  - using shaped boxes that follow casting contours more closely.
  - blocking-in box corners (where appropriate) to reduce the amount of sand required to fill a box.
  - the judicious use of ‘loose pieces’ and inserts to hollow out the mould in non-critical areas.
  - reviewing wall thickness and, in particular, the amount of sand beneath the casting. The use of reinforcing wires or bars may be preferable to excessively thick walls.
  - incorporating lumps of waste sand as a backing material will fill space and reduce binder consumption. An alternative is to use metal spheres cast with metal which would normally be pigged. These spheres must, however, be confined to sand away from the pattern face.
- Increase metal yield by improved methoding. This will allow better use of moulding box space, provide more efficient feeding systems and reduce scrap and waste sand levels.
9.3 USED SAND DISPOSAL/RECLAMATION

Currently, approximately 50% of UK foundries dispose of all their used sand. Considerable scope therefore exists for the further adoption of primary reclamation within the industry.

The main factor limiting the wider adoption of primary reclamation is a general lack of awareness of the true costs associated with sand purchase and disposal. Foundries with low sand use can find it difficult to justify the capital investment. Such foundries are, however, advised to evaluate both the potential cost savings from introducing sand reclamation and the anticipated payback.

Foundries currently using primary reclamation only, should consider using secondary reclamation. Application of secondary reclamation to a proportion of the particulated sand would virtually eliminate the need for new sand purchase and waste sand disposal. The cost savings that can be achieved with secondary reclamation should, in many cases, produce an acceptable payback on capital expenditure.

**ACTIONS TO IMPROVE WASTE SAND MANAGEMENT**

- Evaluate primary reclamation techniques (if not already adopted).
- Consider secondary reclamation techniques where primary reclamation is already used.
- Use the highest amount of reclaimed sand possible in the sand mix.
- Ensure hopper capacity is sufficient to enable the maximum use of reclaimed sand.

The above actions will maximise the amount of used sand which can be reclaimed. For remaining waste sand, foundries should examine sand disposal costs and possible alternative disposal options.
SAND PRICES

There is a considerable spread in the price paid for the different amounts of sand purchased (see inset data in Figs A1 - A4). This is mainly due to differences in packaging costs (bagged deliveries are more expensive than bulk tanker deliveries). Transport distances also affect the price.

Silica sand prices

Most foundries buy silica sand in bulk and already benefit from any associated discounts. This accounts for the inset data shown in Fig A1, which suggests that the price is independent of the amount purchased. The main variable in this case is probably the transport cost.

Zircon sand prices

Zircon sand is imported in bulk marine tankers and the shipping costs are a major contribution to the comparatively high price. In addition, production costs for zircon are relatively high because the raw mineral must be concentrated. The fluctuating price of zircon is due to varying exchange rates, foreign trade policies and weather conditions. The price is therefore strongly dependent on the date of purchase; this is reflected in the erratic data shown in Fig A2. Most, but not all, of the zircon used in UK foundries is supplied in 25 kg bags. Although this leads to increased packaging costs, it is the most efficient way of handling the small quantities typically used by most UK foundries.
Chromite sand prices

Although chromite sand is also imported in bulk marine tankers, there is a large demand for chromite from other UK industries. The supply chain to the UK is consequently larger and does not suffer from sporadic fluctuations in demand. The raw mineral requires little processing and so the production costs are much lower. UK foundries, however, use several different grades of chromite, some of which are not suitable for all alloy sectors. This accounts for some of the spread in the price for different purchase amounts (see Fig A3); the remainder is mostly attributable to variations in transport and packaging costs.

Resin-shell sand prices

Resin-shell sand is manufactured to various specifications using either silica or zircon sand. Particular grades may contain varying quantities of binder (typically 3 - 6% by weight), different nitrogen levels within the binder, and other additives (eg clay, iron oxide, etc). The differences in price shown in Fig A4 are mainly due to the different production costs, although variations in packaging and transport costs also have an effect.
SETTING METHODS USED

The survey revealed that, in the UK foundry industry, moulds are predominantly manufactured using self-set systems (see Fig A5). Heat-cured and gas-hardened organic systems are normally used for the production of small components that require a better surface finish and dimensional accuracy. These characteristics also make these systems popular for core production.

USE OF BINDERS FOR MOULDING

The main factors affecting the choice of binder system are:

- technical requirements;
- price;
- familiarity (foundries tend to stick with the products they know);
- potential for sand reclamation (where large volumes are involved);
- workplace conditions;
- emissions to atmosphere;
- disposal constraints.

Fig A6 highlights the wide variety of primary moulding systems used in the four alloy sectors. The graphs also show the total amount of mixed sand used by foundries with each moulding system.

Moulding systems used in iron foundries

Furane binder systems are apparently more popular among larger foundries, whereas alkaline-phenolic systems seem to be more popular among smaller foundries. A significant proportion of sand from both these systems is already recovered for re-use by primary reclamation. CO₂-silicate is mainly used at smaller foundries where the cost of reclamation plant is thought to be unjustified and the used sand is discarded.

Moulding systems used in steel foundries

One reason for the popularity of the alkaline-phenolic system in steel foundries is the improved working environment, although odour complaints have been known. The use of furane, silicate and resin-shell as a primary system is restricted to a small number of foundries. However, resin-shell is commonly used as a secondary system for the production of small, dimensionally-accurate moulds.
Moulding systems used in aluminium foundries

The quantities of mixed sand produced by aluminium foundries suggests that alkaline-phenolic and CO₂-silicate binder systems are mostly used by smaller foundries. Larger foundries tend to use phenolic-urethane and furane. Alkaline-phenolic, furane and phenolic-urethane binder systems have a high potential for sand reclamation.

The attraction of the CO₂-silicate system for smaller foundries is mainly due to its very long bench life, which permits mixed sand to be stored for long periods prior to use. The binder addition ratio is relatively high (normally around 3.5%), allowing the CO₂-silicate system to tolerate variations in the thoroughness of mixing. The quality of mixing equipment and level of skill required to produce acceptable moulds is consequently reduced. The system also has the considerable advantage of not producing any noxious gases.

A major disadvantage of the CO₂-silicate system is that, because of the high binder addition ratio, sand reclamation is difficult. Consequently, most of the larger foundries have changed to binder systems that may be more expensive but are easier to reclaim. The remaining users of the CO₂-silicate system are smaller foundries where reclamation has not previously been viewed as financially viable.

Moulding systems used in copper foundries

The CO₂-silicate system is most widely used by smaller copper foundries, whereas the larger foundries prefer alkaline-phenolic and resin-shell. Alkaline-phenolic is more commonly used because it is easier to reclaim.
The use of resin-shell as the primary moulding system is restricted to a few specialised foundries. It is, however, a well-established technique for the production of moulds and cores to a high dimensional accuracy; it is easily removed from internal cavities and produces a good surface finish. It is normal to find at least one resin-shell machine or core blower at each foundry, mainly for the production of cores.

USE OF BINDERS FOR COREMAKING

The use of different binder systems for coremaking in ferrous and non-ferrous foundries is shown in Figs A7 and A8 respectively.

Compared to moulding systems, the selection of a coremaking system is less subject to the primary considerations of cost and reclaimability. The survey found that historical precedent and special technical problems associated with the production of certain castings often results in several different core systems being used, with no attempt to rationalise production.

Fig A7 Core binder systems used by ferrous foundries

Fig A8 Core binder systems used by non-ferrous foundries