Shrinkage—mould factors

Shrinkage defects—mould factors

Mould wall movement as a cause of shrinkage defects

How shrinkage occurs

The solidification of grey cast irons involves stages in which the volume of the metal decreases, for example due to liquid contraction or to primary austenite separation, and a subsequent stage at which expansion occurs owing to the precipitation of graphite during eutectic solidification. In most commercially produced grey and ductile cast irons the expansion which occurs during eutectic solidification due to graphite formation more than offsets the decreases in volume in other stages of solidification.

In principle, it should be possible to produce completely sound castings without any feeding.

In practice the extent to which this can be achieved depends upon whether the mould has sufficient strength or rigidity to resist the forces which result from ferrostatic pressure and the expansion occurring during eutectic solidification.

Thus the concept of mould rigidity has become closely related to casting soundness. Moulds of low rigidity are least able to resist the expansion forces acting upon them, dilation of the mould cavity occurs, oversize castings result, and if unfed the castings contain surface and/or internal shrinkage defects. Fig. 1 shows how mould rigidity affects both casting dimensions and the size of external “pipes”.

The effects of mould rigidity upon soundness are shown schematically in Figs. 2 & 3. In the first case (Fig. 2) with a mould of low rigidity the mould cavity enlarges under the action of heat and extra liquid iron is drawn from the feeding or gating systems to compensate for the mould wall movement. If the feeding and gating systems freeze prematurely while mould wall movement is still occurring, porosity and cavities will be formed.

On the other hand with a rigid mould (Fig. 3), when metal is cast, the mould cavity tends to decrease in volume and, in some circumstances, surplus metal can be expelled via the gating and feeding system. This is known as purging. The result is smaller, lighter and sounder castings.

Assessing mould wall movement

The extent of mould wall movement—which can be either expansion to increase the volume of the casting with low rigidity moulds, or contraction with those of high rigidity—can be easily assessed by weighing or measuring the castings produced.

When a series of castings from a production line are examined, and the dimensions or weights are checked, it is very common to find variations in size and weight. This is illustrated by the data in Fig. 4 which relates to weights of grey iron brake drums, for castings taken in random order from a production line. The weights ranged from 73.5–78.5 kg—a variation of 5 kg. The moulds for these castings were all made in greensand mixture on jolt-squeeze moulding machines.

Softer moulds produce heavier swollen castings. Well-rammed moulds produce lighter and more accurate castings.

Thus weighing or measuring castings provides a simple quality control measure which enables foundries to eliminate potentially unsound castings before any machining is undertaken. Heavier oversize castings are almost certain to contain porosity or shrinkage cavities. Sometimes, as shown in Fig. 5 castings may be so badly swollen that weighing or measuring is unnecessary.
Effects of mould type

In the first instance an assessment of the effects of mould type can be made by comparing the dimensions and soundness of unfed castings pouring into different types of mould. Such a comparison is made in Fig. 6. It shows simply that mould dilation and hence shrinkage is most likely in greensand moulds, is reduced in high pressure greensand moulds and is least in fully cured chemically bonded sand moulds.

Performance of different binder systems

Further insight into the effect of mould type can be obtained from actual measurement of changes in mould cavity dimensions as the casting solidifies. Results for flake graphite irons are illustrated in Fig. 7.

With greensand moulds, enlargement of the mould cavity began soon after pouring the casting and subsequently became more pronounced during eutectic solidification. This occurred first because the mould had insufficient rigidity to resist ferrostatic pressure and then because of the forces arising from the expansion of the metal during eutectic solidification. A factor contributing to the enlargement of greensand moulds might be the occurrence of a low strength zone formed by moisture condensation behind the heated mould surface.

With more rigid moulds such as dry sand or, more particularly CO₂ silicate bonded sand moulds, there was a contraction of the mould cavity during the early stages of solidification of the casting due to the expansion of the mould surface as it was heated. This was followed by an enlargement of the mould cavity when eutectic solidification commenced. Overall the change in size was smaller and hence improved soundness.

Similar measurements made with other types of moulds and tests carried out on castings themselves have enabled a ranking to be established which relates to soundness which can be achieved and by implication to dimensional consistency of castings and to metal requirements. This ranking has been expressed in terms of measured density of unfed castings. The higher density shows a more rigid mould, a sounder casting and a reduced need for feeding. This ranking is shown in Fig. 8.

At one extreme, with short curing times, the soundness of the unfed castings produced in acid catalysed sands was similar to that obtained with a greensand. At the other extreme, with longer curing times and with the resin and catalyst contents at the levels required to develop maximum strength, the use of the acid catalysed system produced very rigid moulds and castings which had similar dimensions and soundness to those achieved in cement bonded sand moulds. This demonstrates clearly the danger of the assumption that just because chemically bonded sands are used, an improvement in casting soundness will automatically result.

The phenolic urethane system is characterised by a more rapid development of strength than that obtained in many acid catalysed resin systems, and also by its good through-curing properties. Using this binder much sounder castings were achieved with curing times of less than 6 hours.

The phenolic urethane bonded system ranks high in the order of selection of moulding processes which should be recommended for use to obtain maximum casting soundness with minimum feed metal requirements. This performance might be matched with acid catalysed systems by using special, highly reactive resins and catalysts used with high speed mixers to overcome problems of short bench life.

The performance of the self set silicate bonded sands was generally similar to that of the acid catalysed systems. As with the latter extended curing times were necessary for high strengths to be developed.

Cold box processes hardened by sulphur dioxide or amine gas also resulted in the production of moulds having good rigidity, so these were capable of producing sound castings without requiring the use of extensive feeding.
Shrinkage—mould factors

Soundness achieved using shell moulds was less than that obtained with the other chemically bonded processes. With unbacked shell moulds the castings were less sound than those made in greensand. When the shell moulds were backed with shot there was an improvement to a standard similar to that given by greensand.

Completely sound flake and nodular graphite castings can of course be produced in greensand moulds that are low in the rankings that appear in Fig. 8. This is achieved by designing the gating system to promote favourable temperature distributions in the mould cavity which, together with the use of feeders, to give the required casting soundness. The consequences of the use of rigid moulds is the greater ease with which such soundness can be obtained and the use of less metal, resulting from the production of smaller, dimensionally accurate castings and from reduced feed metal requirements. This may be particularly important for foundries producing nodular graphite iron castings, where yields of the order of 60 per cent are common.

Type of metal cast
Mould wall movement is a “fact of life” in any sand casting process. It will affect to some extent the dimensions and soundness or feed metal requirements of castings produced in any metal. Fig. 9 shows mould wall movement with steel castings produced in green and dry sand moulds.

Movement affects white irons and malleable irons, but the consequences are very much more pronounced in grey irons where there is the additional and almost unique feature of increase in volume during eutectic solidification.

Although the volume of graphite precipitated during eutectic solidification is the same in grey and ductile irons of similar composition, differences in the solidification characteristics of these two types of iron cause much greater expansion forces with the latter (Fig. 10). This is why it is often more difficult to produce sound ductile iron castings than sound flake graphite castings and also, if feeding is required, yields tend to be lower with nodular graphite irons. Compacted graphite irons have intermediate feeding requirements. For this reason it is imperative to use rigid moulds for the production of nodular iron castings, in order to reduce the mould wall movement and improve soundness without having to resort to extensive feeding.

Pouring temperature also affects mould wall movement
Changes in pouring temperature affect the extent of mould wall movement, especially when greensand moulds are used. In such moulds, the higher the pouring temperature the greater the mould wall movement, the larger the casting becomes (Fig. 11) and the greater the risk of unsoundness. The reasons for the increase at high pouring temperatures are:

More heat is transferred to the sand at higher pouring temperatures, so that expansion of the sand is greater and migration of water from the interface is more extensive.

Casting solidification is delayed and this enables the metal to follow changes in mould dimension for a longer period of time.

Control of soundness in greensand moulds

- Compact moulds to a high and uniform density (Fig. 12).
  Use a jolt squeeze action in preference to a free jolt (Fig. 13).
  Preferably pre-jolt prior to simultaneous jolt squeeze (also Fig. 13).
  Do not overload the machine.
  Ensure operation at correct pressures.
  Use strong boxes to prevent distortion.
Use boxes with good reinforcement—ensure that sand between reinforcing bars is well compacted.
Alter machine operational sequences until best results are obtained.
Regularly measure mould hardness on faces and sections of moulds to ensure consistency.

- Control sand composition to obtain maximum compaction
  Keep water content as low as possible (Fig. 14) consistent with other requirements.
  Raise coal dust (or substitute) additions (Fig. 14).
- Reduce ferrostatic pressure and temperature effects.
  Avoid tall feeder heads.
  Pour at temperatures as low as possible without causing other defects.
- Weight moulds so that load is uniformly distributed.

Control of soundness in chemically bonded sand moulds and cores

- Use only fully cured moulds or cores.
  Allow as much time as possible for curing.
  Schedule work so that as far as is possible all moulds and cores cure for the same time.
  For air setting systems choose binders and catalysts which give the highest strength in the available curing time.
  Ensure that this choice is consistent with bench life and strip time requirements.
  Never under-catalyse—required strengths may never be reached.
  Use binder systems as instructed by the manufacturer.

- Monitor strength development on the shop floor.
  Check strength of moulds and cores using the BCIRA Ridsdale impact penetration tester. Ensure that there is a minimum of 40 and preferably 50 impacts per cm of penetration to a total depth of 6 cm with the tester set to trigger at a 14 kg load—see BCIRA Broadsheet 16-15.
  Reject moulds or cores which are surface or skin or which are inadequately through hardened (Fig. 15).
  Alternatively measure strength using the Schmidt hammer (Fig. 16). Ensure that an average reading of over 70 is obtained from six tests at various points on the mould or core surface.

OR

Determine compression strengths on AFS 50 mm (2 in) compression test pieces placed immediately alongside moulds or cores, either covered or uncovered. Strengths of at least 4100 kN/m² (595 lbf/in²) covered or 6900 kN/m² (1000 lbf/in²) uncovered are advisable—see BCIRA Broadsheet 16-15.

Do not transfer compression test pieces to the laboratory for curing. Atmospheric conditions, temperature and relative humidity may be different and will affect rates of strength development.

- Ensure consistency in mixing operations.
  Check sand delivery to the mixer.
  Calibrate and regularly check delivery of resin and catalyst pumps.
  Minimise variations in sand temperature.
  If practicable use sand heaters or coolers to stabilise temperature, the former to reduce catalyst consumption and to decrease costs.
  Know and control amounts of reclaimed sand in mixtures.
- Monitor temperature and relative humidity in the foundry. Curing times can be affected (Fig. 17)
Shrinkage—mould factors

and should be compensated for by changes in resin and/or catalyst addition.

- Use moulds and cores as soon as possible or store in warm dry conditions.

Sodium silicate or acid catalysed sand cores weaken badly if stored under conditions of high humidity.

Shell, hot box and urethane cold box cores also lose strength in high humidity conditions (Fig. 18).

If prolonged storage is necessary protect cores with a sprayed resin based coating hardened by baking.
Fig. 1. Effect of mould rigidity on casting dimensions and soundness.

Fig. 2. Movement and shrinkage in moulds of low rigidity.

Fig. 3. Sound castings from rigid moulds.

Fig. 4. Variation in weight of brakedrum.

Fig. 5. Swollen casting (right) from low rigidity mould.

Fig. 6. Effect of mould type on soundness.
Fig. 7. Expansion curves for grey iron castings in green and dry sand moulds.

Fig. 8. Comparison of soundness using different binder systems.

Fig. 9. Mould wall movement with steel castings in green and dry sand moulds.

Fig. 10. Expansion curves for grey (flake) and ductile (nodular) irons in greensand moulds.

Fig. 11. Effect of pouring temperature upon mould dilation.

Fig. 12. Relation between soundness and bulk density in greensand moulds.
Fig. 13. Effect of mould machine action on bulk density.

Fig. 14. Influence of coaldust and water contents on mould rigidity.

Fig. 15. Typical impact penetration resistance.

Fig. 16. Schmidt hammer.

Fig. 17. Effect of temperature and humidity on curing of UP/PA bonded sands.

Fig. 18. Effect of humidity on the strength of urethane cold box cores.