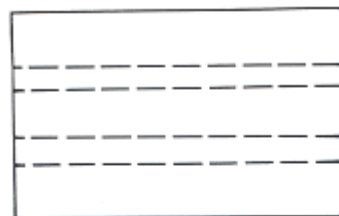


Making a steel casting

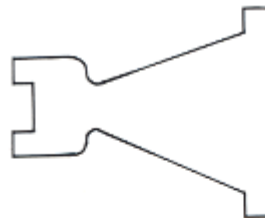
1. Making a steel casting requires a detailed knowledge of metallurgy as well as the craft of the foundryman. This appendix concentrates on the input of skilled craftsmen.

The concept

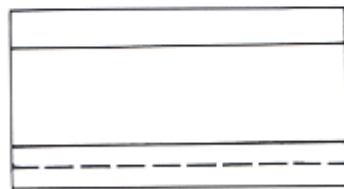
2. Potential customers would usually send a drawing to the steel founder for its comments on design suitability, and for commercial tender. Three views would normally be given of the object: a plan, a side elevation and an end elevation.



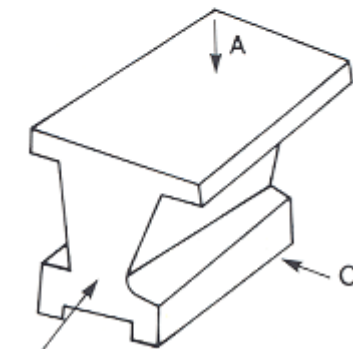
"A" - Plan



"B"
End Elevation



"C" - Side Elevation

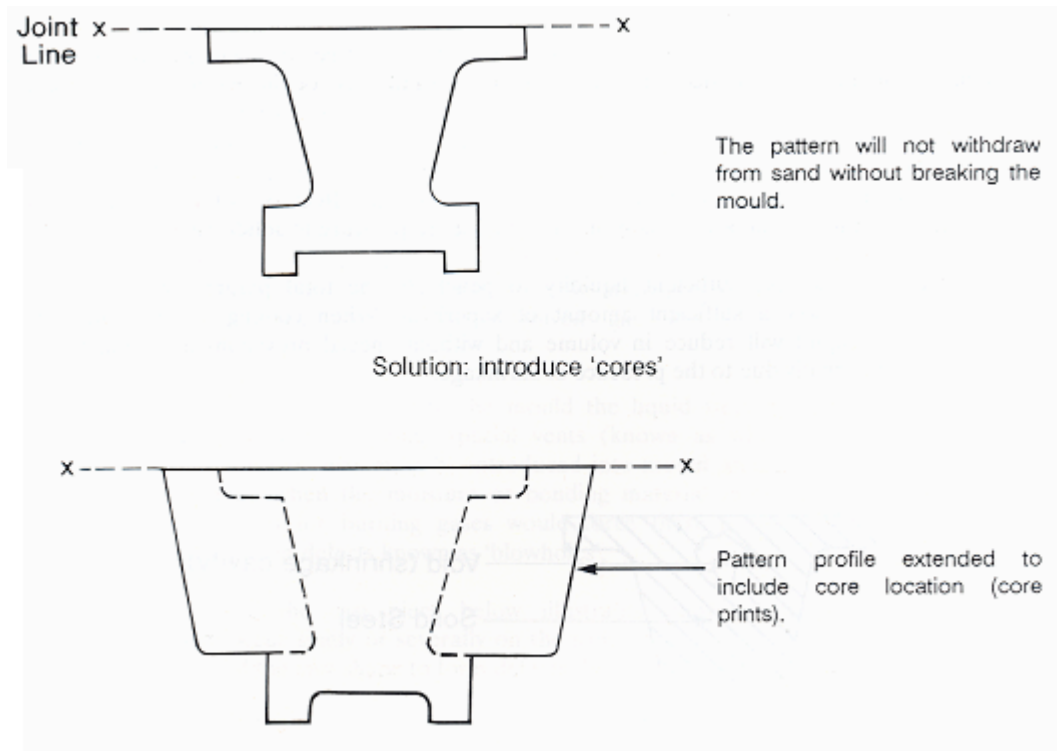


Object

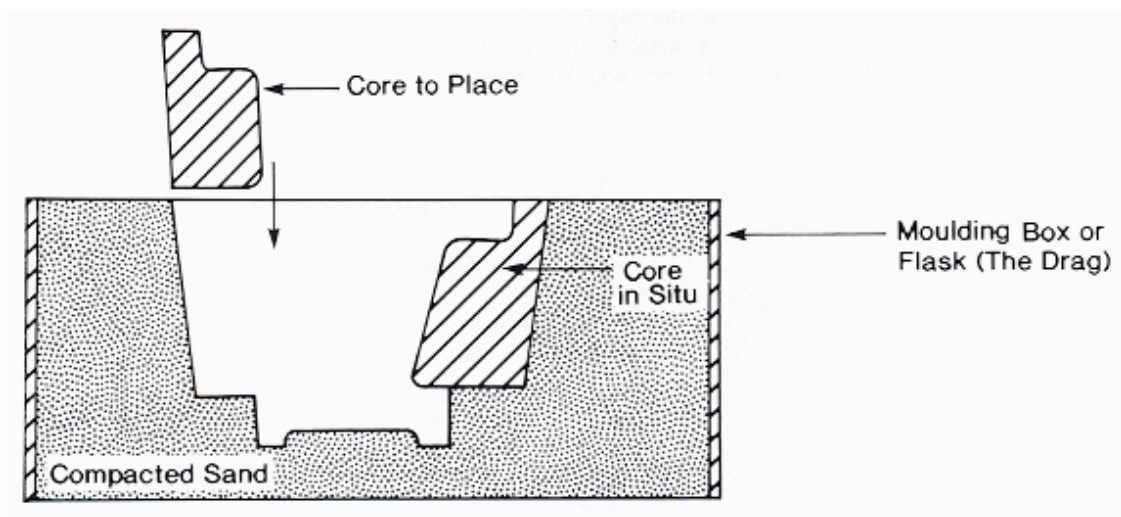
Manufacturing: Stage 1

3. The pattern. The patternmaker produces a pattern which will be used later in the process to construct the moulds into which liquid steel will be poured. At this early stage, consideration is given to the style of manufacture, which of the several available processes will be used, the quantity required, and whether any other allowances are needed due to a speciality aspect of an unusual steel specification.

4. How to mould, ie how to produce sand cavities which accurately retain the contours of the pattern? A major consideration at this stage is the split of a mould into two parts ('cope and drag' or top and bottom) needed in order to extract the pattern from the sand without breaking the mould. Thus the patternmaker sees a joint line.



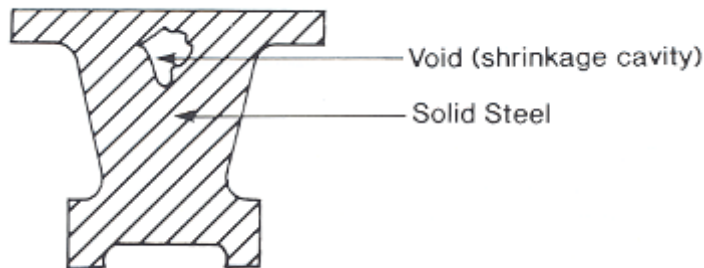
5. Additional sand shapes, or cores, may therefore be required for assembly into the mould after the removal of the pattern and prior to the introduction of liquid steel.



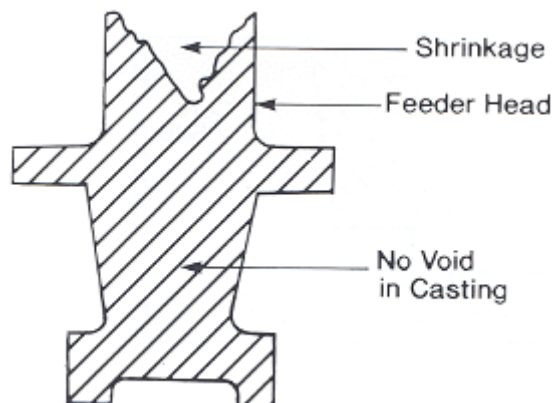
6. Contraction. Steel expands and contracts in response to heating and cooling (due to the reduction in physical size which occurs when steel cools from liquid to solid). For example, a cast dimension of 50" would only measure 49" when cooled from 1,500°C to 20°C. Likewise all dimensions created in a mould would be reduced by 1/50th. The patternmaker thus needs to increase all the dimensions of the pattern equipment by 2 per cent. This is done by using special rules which are manufactured with the appropriate 'contraction allowance'.

7. The problem is more complex than the simple use of a 2 per cent factor. For example, a restraint on the extent of contraction is offered by the sand mass of the moulds and cores, and the often complex design of the steel casting will interfere with a simple contraction factor. The patternmaker will at times use such additional or lesser contraction as he considered necessary, or as a result of dimensional feedback from production samples. A methods engineer may also help in this assessment of the implications of the effect of volumetric contraction which occurs in liquid metal as it cools from the pouring temperature to solidification.

8. In order to achieve sufficient liquidity to penetrate the total parameters of a mould, liquid steel must carry a sufficient amount of superheat. When cooling to its solidification temperature the liquid will reduce in volume and without special provisions a casting is likely to be defective internally due to the presence of shrinkage.



9. To prevent the occurrence of shrinkage cavities in cast shapes, the methods engineer may suggest additional rigging to the patternmaker. The additional rigging is in the form of more patterns which will create holes in the top half of the mould (cope), acting as reservoirs of molten steel to supply extra liquid metal to the casting as it cools from liquid to solid. The term feeder heads or risers are used to describe these parts.



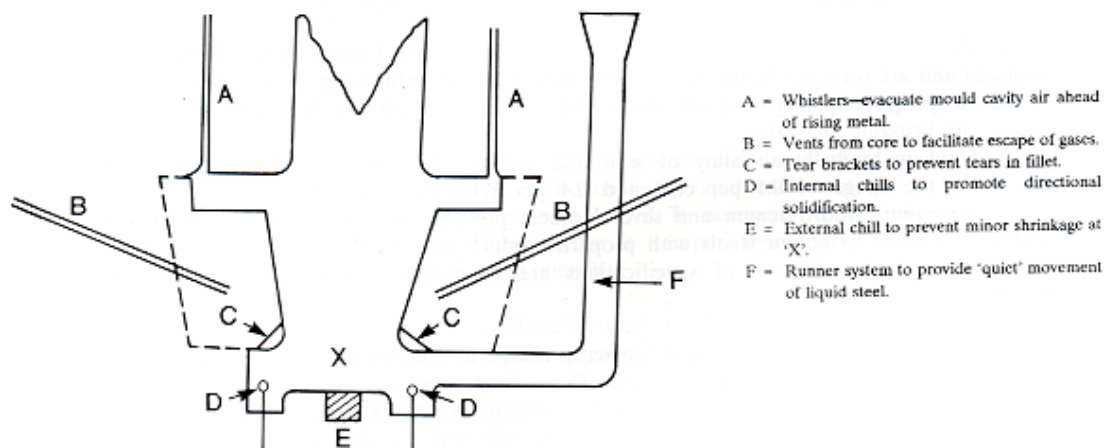
10. The methods engineer will also consider several other factors, including the ability of later processes to remove the feeder material which is obviously surplus and unwanted after it has functioned. He will also try to assess the likelihood of other possible defects due to cooling and contraction, such as minor shrinkage and tears which require the provision of chills and position of anti-tear brackets.

11. The methods engineer endeavours to produce a design which is most likely to create directional solidification means by which the remote parts of the castings are the first to solidify and successively solidification continues progressively towards the feeder(s). If successful, when the casting is solid all shrinkage will reside in the riser which is subsequently discarded.

12. The means of entry of the molten steel into the mould is a further consideration. Special channels (runners and ingates) must be formed to effect 'quiet' entry of the liquid steel. Turbulent entry would create defects from erosion of the mould material (inclusions), entrained gas (trapped air) and absorbed gas from the atmosphere, which would dissolve in the liquid and cause effervescence as the dissolved gas was liberated at the stage of solidification.

13. To accommodate perfect entry to the mould the liquid steel must displace the mould cavity air. This is done by positioning special vents (known as whistlers) at high places in the mould. Another form of vent must be introduced into mould and core masses to allow the escape of gases formed when the moisture or bonding material in the sand becomes heated. Insufficient escape routes for burning gases would force these gases to blow back into the still liquid castings and form defects known as 'blowholes'.

14. The diagram of the cast piece below illustrates many of the features mentioned previously which can occur singly or severally on the same casting depending upon the estimated potential or tendency of the cast shape to form defects during pouring or cooling.



15. These simple illustrations outline the things the patternmaker needs to consider when he crafts a pattern which will accurately and repetitively produce sand shapes for complex 'three dimensional jigsaws'.

Manufacturing: Stage 2

16. The mould. So far all activity has occurred in the pattern shop. Moulds are produced from the patterns by a variety of processes. Such systems as greensand, cold set, shell mould, boxless moulds, core assembly and many others, all have their particular uses and specific advantages in terms of production economics and product quality. The pattern equipment is directed to the most appropriate production facility.

17. As cores will be required before moulding operations can be completed it is normal to produce them ahead of the moulding activity. In repetition foundries the core-making function is normally mechanised. The modern processes use machines which 'blow' a sand mix (ie sand and binder resin) into a corebox followed immediately by the 'injection' of a gas catalyst which causes the resin to solidify. This effectively hardens the sand in the corebox and the core can be extracted, handled and moved into storage ready for later use with an appropriate mould.

18. A similar process of sand and resin plus catalyst (either combined liquid or gas) can be used for the production of mould parts (copes and drags). The most common system, however, is the greensand process. This system uses silica sand plus a clay (bentonite) plus a cereal (starch) and water. Close control of additions of clay, cereal and water will produce an ideal medium for mould making after being processed in a sand muller for 3 minutes. The sand is delivered to the moulding station where cope and drag flasks are accurately positioned on the separate halves of the pattern equipment. A high pressure hydraulic squeeze is applied to the sand to achieve maximum compaction. After release of the squeeze the sand remains firmly compacted in close contact with the pattern. The patterns in the cope and drags are accurately drawn clear of the moulds which then progress to the next stage closing. If appropriate, the pattern is then recycled and mould production repeated.

19. This stage in the production process ends with an inspection of the mould and the introduction of core, prior to the placement of cope on drag to complete the closure of the mould, which is then ready to accept liquid steel (the cope is frequently secured to the drag to provide a 'liquid metal tight' joint). Additional functions may occur during closing, such as the placement of chills, cutting brackets, insertion of vents and whistler channels. The moulds are then moved to a pouring station. Moulds must be produced and presented in batches which relate to the furnace batch size and sorted into an order so that batches take metal of the same specification.

Manufacturing: Stage 3

20. The metal. Liquid steel can be produced in several furnace types high frequency furnaces and arc furnaces being the most common. Small quantities (up to 3 tonnes) are usually produced by high frequency methods. All melting systems these days are electrically powered.

21. Steel is basically an alloy of iron and carbon. The carbon addition is very small, usually in the range of 0.1 per cent and 0.4 per cent, but the addition of alloys such as nickel, chromium, molybdenum and several others presents endless possibilities for designers and metallurgists to obtain steels with properties which are exactly in line with the intended use of the casting. Dozens of specifications are in regular use and the choice is from hundreds.

22. When the furnace has reduced the scrap charge to a liquid state a sample is checked by automatic spectrographic chemical analysis. These large expensive instruments are referred to as 'polyvacs'. Some 20 elements are checked to ensure that there are no deleterious elements present, and to calculate the amount of alloy additions needed to satisfy the required specification. Additions of alloys are made to 'bring the metal into spec' and after a final analysis check the liquid metal is temperature corrected and poured into a dispensing ladle. Special additions of aluminium are made to the metal at this stage to liberate any oxygen which may be dissolved in the steel.

23. A special team of men is responsible for the transfer of liquid metal to the mould (known as 'teeming'). The metal is carried in a ladle which incorporates a plug (stopper) capable of being raised and lowered to enable metal to flow and stop as each mould is filled.

Post-cast processes: Stage 4

24. The casting is now made and after a short period of cooling (say 30 minutes) the casting is separated from the sand by shaking the total mould. The loosened sand is collected for recycling or disposal. The cast shape is now available for any further processes.

25. The fettling activity. At this stage of manufacture, ie after 'knock-out', steel castings have used about 50 per cent of the man-hours of the total process. (This is significantly different from cast iron castings which only require a minimum amount of work after knock-out.)

<i>Shot blast</i>	Metal shot is 'blasted' at castings to remove all sand.
<i>Head removal</i>	Risers (heads) and runners etc are detached either by break-off (hammer) or by cutting with oxyacetylene torches (the discarded material is collected, graded, and returned to the furnace for remelt).
<i>Arc air</i>	After riser removal, the remaining 'stubs' of material are removed. The creation of an electric arc by contacting a carbon electrode with the excess metal allows a powerful airstream to blow away the liquid metal pool formed by an arc at the point of contact. Skilled operators recover the profile of the casting which was lost due to the earlier placement of risers.
<i>Welding</i>	It is usually necessary to rectify surface blemishes by the deposition of matching weld metal at any place on the casting which is seen to be defective. Such blemishes are primarily the result of contraction tears, cold laps (caused by lack of fusion of converging metal streams) and inclusion of exogenous material (either sand or slag).
<i>Grinding</i>	Welded areas are ground back to profile as is any other remaining excess metal caused by joint line and core locations (flash).
<i>Heat treatment</i>	<p>The steel in the 'as cast state' may not possess the qualities of strength, ductility, shock resistance and hardness which are intended by the specification, and these properties can be achieved by subjecting the castings to an appropriate heat treatment.</p> <p>By heating to approximately 1,000°C the steel is homogenised; a controlled rate of cooling, either slow (cool in furnace) or in air, or in a quenchant liquid (oil or water) imparts the physical properties which are sought. These treatments are called annealing, normalising and quenching respectively. Following a rapid cool, castings are extremely hard and highly stressed and it is necessary to re-heat them to a somewhat lower temperature to 'temper' them back. This is tempering which always follows a quench.</p>
<i>Post-heat treatment</i>	<p>A hardness check (Brinell) is given after heat treatment. This confirms whether or not the heat treatment was satisfactory.</p> <p>The castings are heavily 'scaled' as a result of the heat treatment and require a further clean up by shot blasting.</p> <p>Inspection may reveal distortion from time to time and require a straightening operation using a hydraulic press.</p>

26. The post-cast or fettling processes described above are only an outline and many deviations and extensions can occur.

27. High integrity steel castings are the result of an extension to the post-cast activities described above. When the consequences of the failure of a steel casting in service could be disastrous then quality guarantees are required. Surface and volumetric inspection of the casting will detect the smallest defects; methods of detection include ultrasound, X-rays, magnetic fields and penetrating dyes. Such examinations and subsequent rectification (upgrading) can entail very significant increases in castings production costs and process times.