Copper Development Association

Designing Aluminium-Bronze Castings

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Copper Development Association is a non-trading organisation sponsored by the copper producers and fabricators to encourage the use of copper and copper alloys and to promote their correct and efficient application. Its services, which include the provision of technical advice and information, are available to those interested in the utilisation of copper in all its aspects. The Association also provides a link between research and user industries and maintains close contact with other copper development associations throughout the world.

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Introduction

Ease of casting, excellent mechanical strength, high damping capacities and high corrosion resistances combined with low magnetic permeabilities make aluminium-bronze castings very attractive to engineering designers. Harry Meigh[*] [*]discusses their design advantages.

These notes and design considerations apply mainly to sand castings but the general principles are valid whatever the mould material.

There are four main aluminium bronze cast alloys:

- The high strength nickel-aluminium bronze which is by far the most popular sand cast alloy. (BS 1400 AB2).
- The lower strength, (low-nickel) aluminium bronze used mostly in diecasting. (BS 1400 AB 1).
- The low magnetic permeability aluminium-silicon bronze. (DG S129).
- The high manganese-aluminium bronzes used mostly as an alternative to nickel-aluminium bronze in ships propellers. (BS 1400CMA1 and2).

Attractive combination of properties

Provided techniques are used which take account of the special characteristics of these alloys, aluminium bronzes are readily castable. High-integrity castings can be produced by the various techniques of sand, shell, die, ceramic, investment, centrifugal and continuous casting. They offer a very attractive combination of properties which compare favourably with other alloys, both ferrous and non-ferrous, of comparable price. Cast aluminium bronzes are well known for their strength. The first and last alloys in the list are as strong as medium-grade carbon steels and stronger than most stainless steels. They also have exceptionally good shock resistance and will deform rather than break. Damaged propellers for example can be straightened without loss of strength .

Due to their restricted freezing range, aluminium bronzes solidify into a compact material; thus, when cast free of defects, they are inherently pressure tight. They can be incorporated into small or large welded assemblies of cast and wrought parts. Damaged castings can be readily repaired by welding. Post-weld heat treatment is rarely necessary except for service in the most severe conditions.

The outstanding corrosion resistance of aluminium bronzes in marine and chemical processing environments is due to the formation of an intrinsic, tough adherent film of aluminium oxide. Furthermore, the nickel-aluminium bronzes have excellent resistance to stress corrosion and corrosion fatigue. Unlike the manganese bronzes, high-tensile brass and other brasses, nickel-aluminium bronze castings are highly resistant to stress corrosion cracking. They are also rarely, if at all, susceptible to pitting, and are generally far more resistant to selective attack.

Aluminium-bronze castings possess exceptional resistance to fatigue, which is one of the most common causes of deterioration in ocean engineering equipment. They are suitable for all air

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and steam conditions up to 400°C. They do not 'scale' at high temperature and their combination of corrosion and oxidation resistance, plus good creep and fatigue properties at elevated temperature, is ideal for high-temperature service. Special alloys with a high aluminium content perform well as glass mould tooling where good thermal conductivity improves production speed.

Nickel-aluminium bronze has a greater resistance to cavitation erosion than cast steel, Monel alloys and the 400 and 300 series of stainless steel. By the same token, it has excellent resistance to impingement attack by gas bubbles. These characteristics make it particularly suitable for propellers, pump impellers and casings and turbine runners, giving them long service lives and optimum operating efficiency. Aluminium-bronze castings are twice as effective as steel in their ability to dampen vibrations. Although more resistant to impingement attack by abrasive substances than grey cast iron and gunmetal, they are more vulnerable than the cast and stainless steels. Filtration is sometimes necessary, therefore, in the case of high-speed pumps requiring the good corrosion and cavitation-erosion resistance properties of aluminium bronze, but which have to handle water contaminated by sand or other abrasives.

Within certain conditions of speed, loading and lubrication, aluminium-bronze castings have excellent wear properties. This makes them suitable for certain types of bearings and gears and for special applications, such as paper making machinery and gear selector forks for motor vehicles. Non-sparking characteristics, coupled with strength, make these castings suitable for safety tools and for equipment used in the handling of explosives, in mines, petroleum and chemical plant, for gas equipment and other similar applications.

Their very low magnetic permeability make the aluminium bronzes particularly suitable for naval applications.

Unlike stainless steels, the aluminium bronzes are readily machinable. This is an important factor to bear in mind when making cost comparisons. Also, with a lower density than most other bronzes or steels, a casting of given dimensions in aluminium bronze can be 5 to 10% lighter. At the same time, the higher strength of aluminium bronze may permit the use of thinner sections - dependent on foundry considerations - providing further advantage.

Conditions affecting casting design

The limitations on the shapes that can be produced in the cast form are imposed by the physical conditions that are necessary for the metal to solidify free of internal defects. There are also minimum sectional thicknesses imposed by the fluidity of the molten metal and by the mould material. An understanding of the solidification process and a knowledge of these limitations due to fluidity are essential to the designer of castings.

Close co-operation between the designer and the founder cannot be overstressed. The designer cannot be expected to have acquired the thorough familiarity with the foundry techniques which are essential for the production of high-quality castings. The following recommendations are therefore aimed primarily at pointing out those aspects of casting design for which consultation with the experienced founder is most essential:

Shrinkage

While most defects in castings can be avoided through good foundry practice, shrinkage is the most important factor which affects the soundness of a casting. The design of a casting has, as will be seen, a crucial bearing on the avoidance of shrinkage defects.

Metals experience three stages of volumetric contraction or shrinkage: as they cool in the liquid state; as they freeze; and, as they cool from their freezing point to ambient temperature.

With regard to these the following points should be noted:

- Liquid contraction does not affect product quality.
- Shrinkage on freezing, on the other hand is very significant from the point of view of obtaining sound castings. It will be seen in the sections that follow that if this shrinkage effect is not properly taken into account in the design of a casting and in the method of pouring it, shrinkage defects will result. Aluminium bronze shrinks approximately 4% volumetrically on freezing.
- Solid contraction affects dimensional accuracy and has other implications which will be discussed later.

Solidification process

Alloys fall into two categories: those with a short freezing range such as the aluminium bronze alloys and those with a long freezing range such as gunmetal. The short freezing range alloys pass almost directly from the liquid to the solid state as do pure metals, whereas long freezing range alloys change from liquid to a kind of pasty condition before becoming solid. This difference is very significant as it has implications for the design of a casting and for the techniques used for producing sound castings.

When molten aluminium bronze is poured into a mould, freezing of the metal begins at the mould face and proceeds towards the centre of the section until it meets the front of solid metal advancing from the opposite mould face. By contrast, in the case of a long freezing range alloy such as gunmetal, the process of solidification begins with a multitude of tiny particles or nuclei dispersed throughout the molten metal which grow simultaneously until the whole mass has solidified. During its transition from liquid to solid, the metal is a pasty mass of solid and liquid existing together. When the last film of liquid metal that surrounds the solid crystals solidifies, it shrinks leaving a labyrinth of microcellular sponginess throughout the material. This contrasts markedly with aluminium bronze, where progressive solidification from the mould face inwards produces compact material with a density approaching the theoretical maximum. This is provided shrinkage defects are not allowed to occur.

Solidification of aluminium bronze

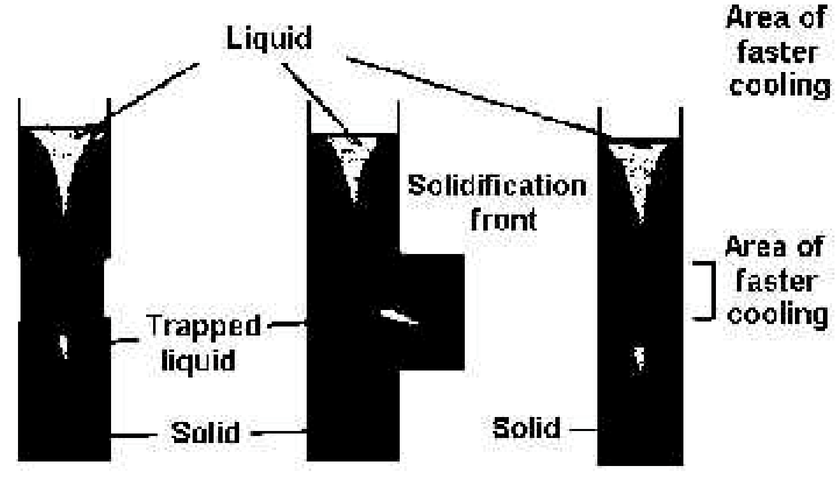
If a casting is to solidify soundly throughout, it is essential that it be poured so that a temperature gradient is established from the lowest point of the mould to the top, where the feeders are. Solidification will thus proceed progressively from the bottom of the mould where the metal is coolest to the top where the metal is hottest. This is known as directional solidification. The advancing solidification front will be in the form of a V as illustrated in Fig 1. This V-shaped front is due to the metal freezing from the surface of the mould inwards and the fact that the nearer a given point is to the bottom of the mould, the further forward solidification will have progressed inward from the mould face.

Anything which may cause premature freezing ahead of the solidification front will trap a quantity of molten metal behind it. When this metal eventually freezes, it will shrink and, since it is cut off from a compensating supply of liquid metal, it will form shrinkage cavities on freezing. This may happen in a variety of ways. It may be caused by:

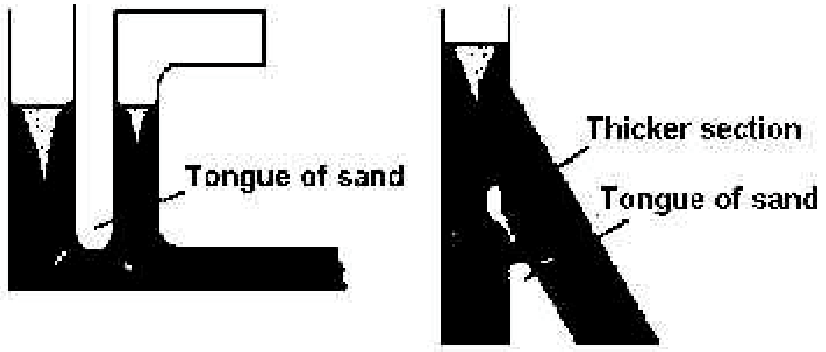
- local thinning of the section (See Fig 1a);
- an isolated mass of localised heavier section (see Fig 1b);
- variations in the heat-absorbtion characteristics of the mould material - the effect of this would be similar to that shown in Fig 1c;

- a 'hot spot'. This expression is used in this article as indicating a point in the mould where the sand has been saturated with heat and is delaying the solidification of the adjoining metal. This usually happens where a tongue or narrow promontary of sand is surrounded by metal on several sides. It can also occur where a thin wall of sand is sandwiched between two walls of metal or where a core is too small in relationship to the mass of metal surrounding it. The effect of a hot spot is shown in Fig 1d.

Figure 1 – How defects can arise in castings



a Local thinning   b Isolated mass   c Uneven cooling



d Hot spot caused by tongue of sand

e Hot spot caused by combination of tongue of sand and thicker section

Two or more of these effects may occur together at a given point in the mould. For example, at the inclined wall junction illustrated in Fig 1e there is both a local thickening caused by the junction and a hot spot caused by the steep junction angle.

The foregoing is the generally accepted explanation of the way shrinkage defects arise in aluminium-bronze castings. According to this theory however, the defects should be concentrated at the centre of the section unless there is a hot spot effect. In practice, shrinkage defects are often found to extend from a few millimetres inside one face to a few millimetres inside the opposite face. Occasionally they break through to the surface at hot spots or due to stresses.

This suggests some shrinkage defects form not at solidification but by a differential contraction effect between the rapidly cooled outer layer of the section and its slower cooled centre. This differential solid contraction effect could, in certain circumstances, give rise to a form of internal hot tear.

It should be said, however, that whatever is the explanation of defect formation, experience shows that they can be avoided by taking steps to ensure the directional solidification of the casting.

Designing to avoid shrinkage defects

Employing design guide lines to avoid shrinkage defects need not over-restrict freedom of design since the founder has a choice of techniques. But it is clearly desirable to design so as to minimise problems as far as possible. It must also be recognised that there are occasions when there is no way, other than by a change of design, of preventing a shrinkage defect occurring. The laws of nature can be channelled but not ignored.

Simplicity of the shape

The shape of the casting should be as simple as its function will allow. It should be designed as a casting and not as a 'cast fabrication'. Figure 2a shows a casting designed as a fabrication and Fig 2b shows a simplified re-design of the same casting. Occasionally it may be an advantage to weld on such features as mounting brackets, machining lugs, webs and ribs. This not only avoids cast wall junctions with its attendant danger of creating 'hot spots', but it may mean that one basic casting design can be used on a variety of applications. It also saves pattern costs.

Taper

It is desirable for wall thicknesses to be slightly tapered in the direction in which solidification is planned to take place. This can often be achieved by tapering the machine allowances and thus leave the basic design unaffected or only partly affected.

Relationship of thin to thick sections

Where the wall thickness of the casting changes, care must be taken to ensure that solidification can proceed progressively from thinner to thicker sections, within an overall pattern of directional solidification for the whole casting. It is desirable to design the casting with this in mind. Thus, in the case of the flanged-pipe junction illustrated on Fig 3, there is a gradual transition from thin to thick sections. The thicker flanges can then act as 'feeders' to the body and are themselves fed by feeder heads. It should be noted that the practice of tapering the wall of the casting towards the flange must not result in excessive thickness at the root, or else it gives rise to shrinkage defects in the root.

The more complex the shape of the casting, the greater the need for consultation with the experienced aluminium-bronze founder, if a pattern of directional solidification is to be achieved throughout.

Figure 2 - A casting designed (a) as a fabrication and then (b) redesigned as a casting

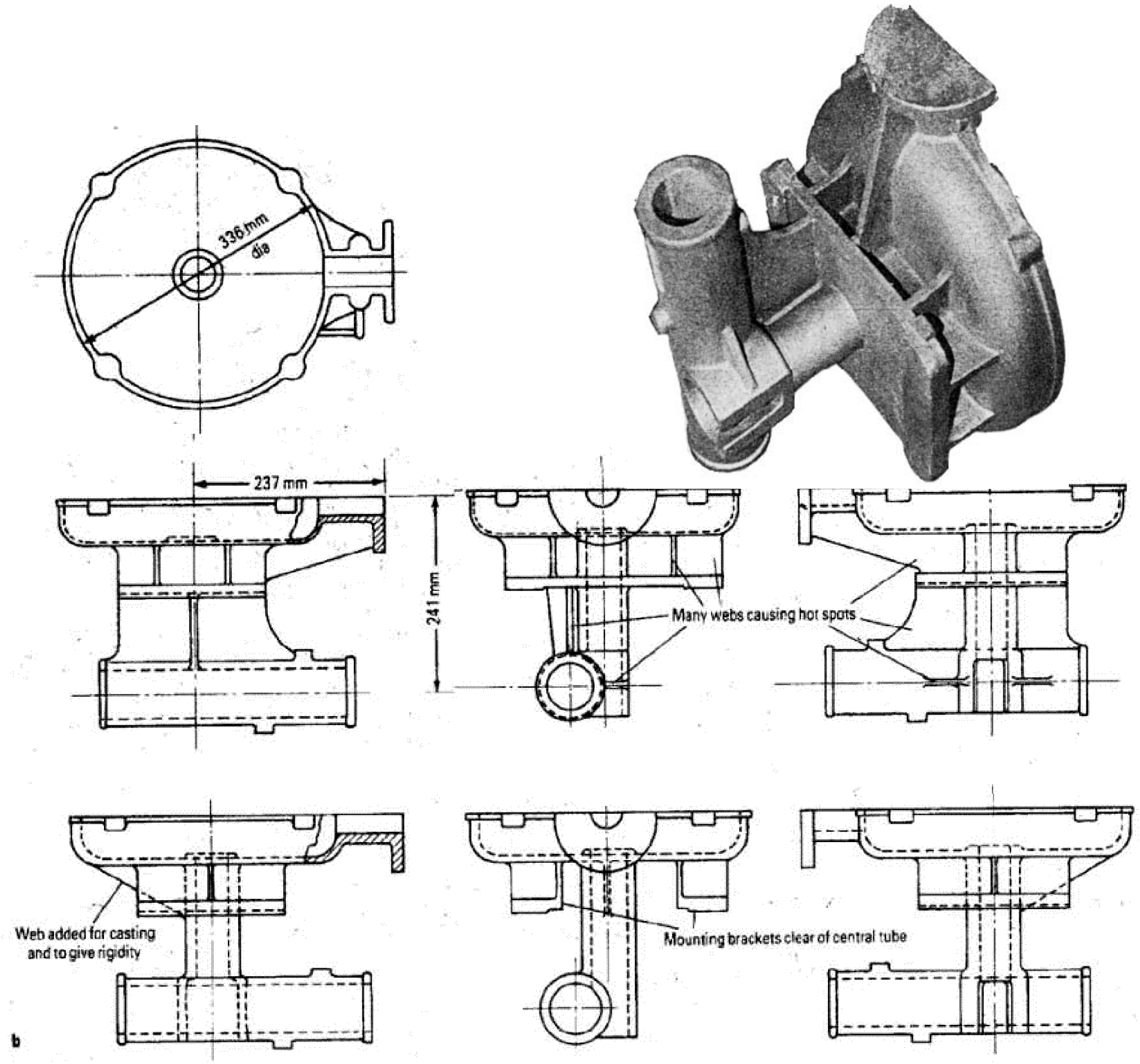
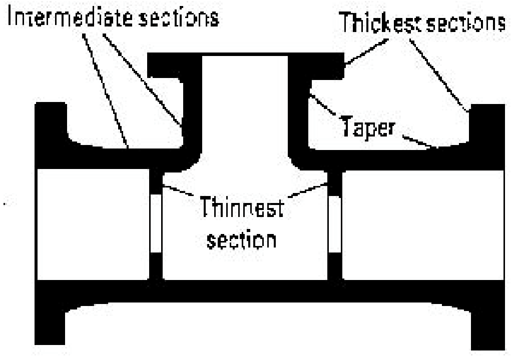


Figure 3 – A design illustrating progressively thickening sections



Wall junctions and fillet radii

Wall junctions fall into five categories: L-, T-, V-, X- and Y-shaped junctions or variants of these. In each case an increase in mass results at the centre of the junction as is illustrated by the inscribed circle method. See Fig 4a. It will be seen that the biggest increase in mass occurs with V, X and Y junctions. If the walls are of unequal thickness, as in Fig 4b, the resultant increase in mass at the centre of the junction is smaller. Furthermore, as explained earlier, unequalled wall junctions can be advantageous with an overall pattern of directional solidification.

Wall junctions also result in parts of the mould being in contact with molten metal on two sides at once. In the case of V and Y junctions tongues of sand are formed which are liable to give rise to hot spots. For all of these reasons it is preferable to avoid V, X and Y junctions. Wherever possible an L junction should be converted into a curved wall of constant thickness or gently tapering from one thickness to the other (see Fig 5). The fillet radii of junctions should be large enough to prevent the creation of a hot spot, but not so large as to increase unduly the mass at the centre of the junctions. As a general guide, fillet radii should be equal to half the wall thickness or half the thickness of the thinner wall in the case of a junction of uneqaual wall thicknesses. When in doubt the founder should be consulted.

The designer must bear in mind that the founder will need to ensure that the increased mass at the centre of a wall junction will solidify directionally and that he may therefore request some modification to the shape of the casting.

Figure 4 – (a) Circles show increased mass at junctions of walls of uniform thickness (b) smaller increase in mass at intersection with junctions of unequal wall thickness

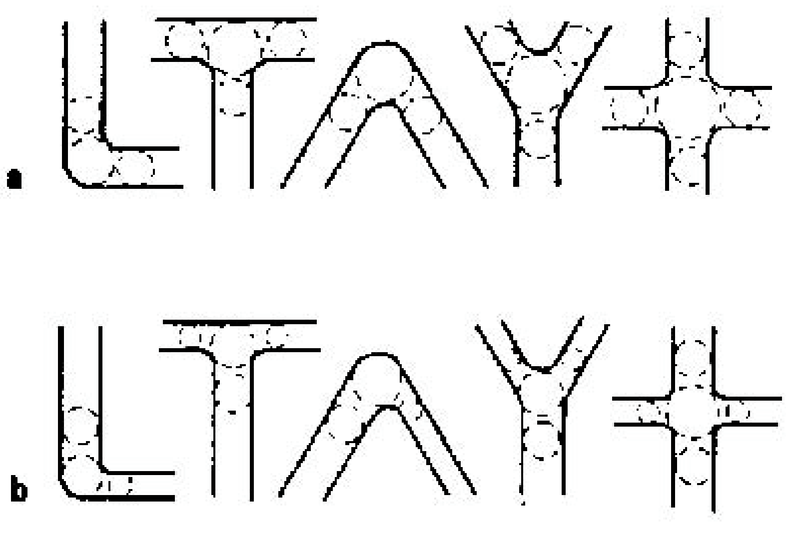
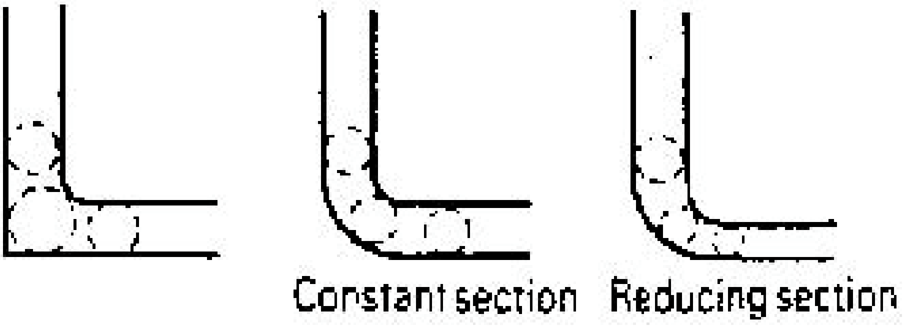


Figure 5 – Replacing sharp 'L' junction by curved wall

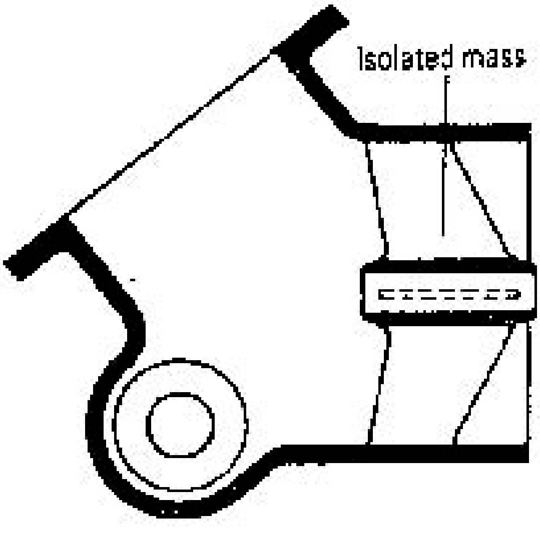


Isolated masses

The size, shape and location of isolated masses such as bosses is important. If they can be located in such a way that they can conveniently be connected to a feeder, so much the better. Otherwise, they must be of a size that can be effectively chilled. This is normally done by means of a metallic insert in the mould at the point where a faster cooling rate is required. Care must be taken in locating bosses that tongues of sand will not be created in the mould, which will give rise to hot spots. This can happen for example, if a boss is located too close to a flange, unless it is merged into the flange.

It is sometimes necessary in certain castings, such as pump castings, to incorporate certain shapes in order to ensure a non-turbulent flow of the liquid through the casings. These may give rise to isolated thicker sections which are liable to shrinkage defects. Another typical case of isolated mass is the spindle guide of a valve, shown in Fig 6. The size of the central boss and the thickness of the supporting web in relationship to the wall thickness of the body is critical. In all such cases, consultation with the founder is strongly recommended.

Figure 6 - Example of an isolated mass: the spindle guide of a valve



Webs and ribs

The use of strengthening webs and stiffening ribs should, as far as possible, be avoided. They may sometimes be advantageously replaced by curved wall sections of uniform thickness, as shown in Fig 7. The relatively low elastic moduli of aluminium bronzes however, makes the use of webs and ribs occasionally essential, to obtain rigidity in certain applications.

If it is necessary to incorporate ribs and webs in the design, they should be thinner than the parts to which they are connected and be normal to them in order to avoid sharp tongues of sand in the mould. A hot spot can be avoided by means of a cutaway as shown in Fig 8. Alternatively, consideration could be given to welding on ribs and webs.

Figure 7 - Replacing a rib by a curved uniform section.

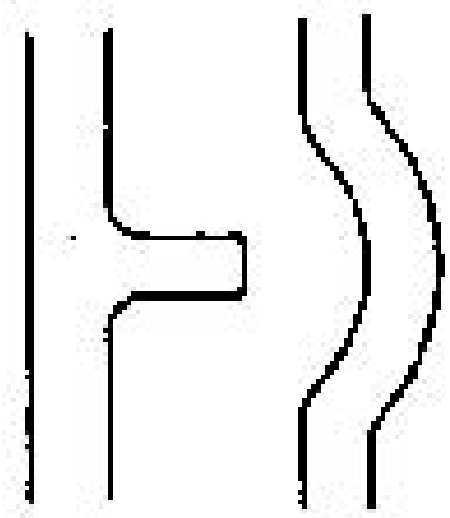
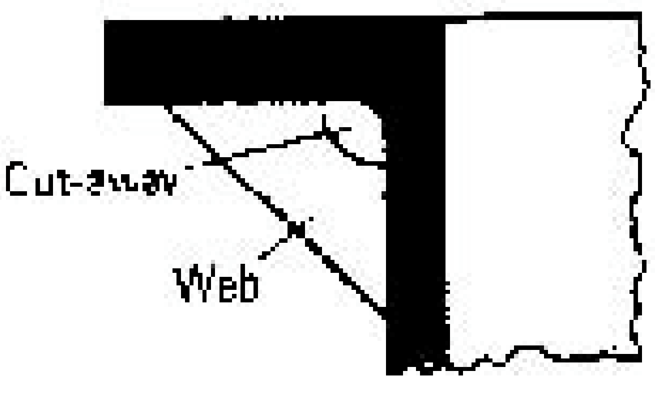


Figure 8 - Cut-away in a web to avoid hot spot



Cored holes

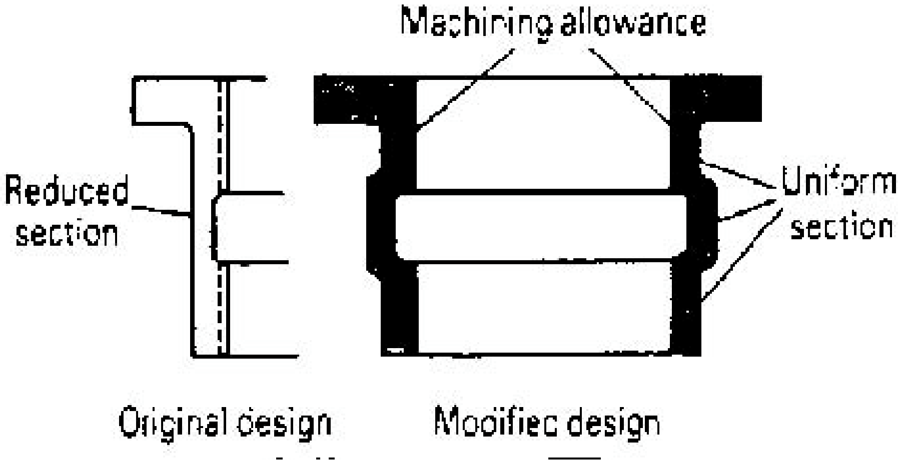
Since cores are almost completely surrounded by metal, care must be taken to ensure that they do not create hot spots. This is liable to happen if the thickness or diameter of a core is too small in relationship to the thickness of the metal surrounding it. Consultation with the founder here is most important. There are, in any case, other aspects of core design, such as core supports and adjustment to shape to promote directional solidification, which may need to be discussed.

When a hole of small uniform diameter is required in a casting, it is better and often cheaper not to core it out but to leave it to be drilled when the casting is machined.

Effect of machining allowance

It is important to bear in mind the effect of machining allowances on the pattern of wall thicknesses required for directional solidification. Figure 9 illustrates the case of a casting where the addition of a machining allowance would have resulted in undesirable changes in cast wall thickness. By thickening up the non-machined parts, a constant thickness is achieved in the as-cast condition.

Figure 9 – Design modified for uniform section as cast



Other design considerations

Fluidity and minimum wall thickness.

The presence of the skin of aluminium oxide partly restricts the fluidity of molten aluminium bronze. Furthermore, if the metal momentarily ceases to rise in any part of the mould during the pouring operation, the oxide skin may prevent it resuming its rise. The metal will then tend to flow over the affected part but will not merge with it because of the presence of the film of oxide. This will leave a 'cold shut' in the casting.

The minimum wall thickness which can be cast without the risk of cold shut is dependent on the casting temperature and on the distance the metal has to flow through a particular thin section in relationship to its proximity to a thicker section or to a runner. It is also a function of the distance of that part of the mould from the point of entry of the metal into the mould.

The minimum allowable wall thickness is, therefore, a function of the size and complexity of the casting, of the running method used and of casting temperature. Table 1 gives recommended wall thicknesses for cylindrical shaped castings of various diameters and lengths. This may serve as a guide for other shapes of castings. It must, however, be borne in mind that, in more complex castings, the metal may have to travel further to fill internal features, such as vanes and partition walls, and the outer wall may, therefore, need to be thicker. This is an area where the designer needs to acquire experience of what is practicable through consultation with an experienced founder.

Table 1 - Minimum castable wall thickness (mm) for sand-cast cylinders

Diameter mm	**Length ,m**							
	76	**152**	**305**	**610**	**1219**	**1829**	**2438**	**3048**
76	6	8	9.5	11				
152	8	9.5	9.5	11	14			
305	9.5	9.5	11	13	14	16	19	22
610	13	13	14	14	16	17.5	19	22
1219	13	14	14	16	16	17.5	19	22
1829	14	16	16	17.5	19	19	22	22
2438	-	19	19	19	22	22	22	25
3048	-	19	19	22	22	22	25	25

Weight saving

Advantage should be taken of the inherent strength of aluminium bronze to avoid excess weight. Allow for the degree of fluidity of the metal and the need to achieve directional solidification throughout the casting. This means that weight must be kept down to a minimum in certain parts of the casting and added to in others, if a defect-free casting is to be produced overall. If the original design is drawn with the smallest wall thicknesses for the satisfactory peformance of the component, a competent aluminium-bronze founder can increase thicknesses to the least amount required to make a sound casting.

Effect of thickness on strength.

The tensile strength given in specifications relates to the strength of a standard 1-in (25-mm) dia test bar and is a function of its speed of solidification and cooling rate. Parts of a casting which are cooled faster than the standard test bar will have improved tensile properties whereas parts which take longer to cool will have lower tensile properties. Table 2 illustrates this point in the case of a standard nickel-iron-aluminium bronze alloy cast in sand.

Table 2 - How thickness affects strength

Wall thickness, mm	**Ultimate tensile strength, MN/m2**	**Elongation, %**
5	708	29
8	662	26
9.5	646	24
19	631	21
38	585	18½
76	569	18
152	538	18

The designer needs therefore to bear in mind the effect of cooling rate on tensile strength in his calculations.

Hot tears and contraction cracks

Unlike cast steel alloys, aluminium-bronze alloys cast in sand show little tendency to hot tears and contraction cracks, provided the casting is sound. This is due to the exceptional ductility of aluminium-bronze alloys at high temperatures. In practice this means that if the wall thickness of a casting is insufficient to give it strength to crush the sand, it will normally stretch without tearing or cracking, provided there are no defects in the casting which could lead to cracking under stress. This applies whether the sand, which is restraining contraction, is a core or a part of the mould. The heavier the section however, the greater its strength and therefore its ability to crush the sand and undergo its full contraction.

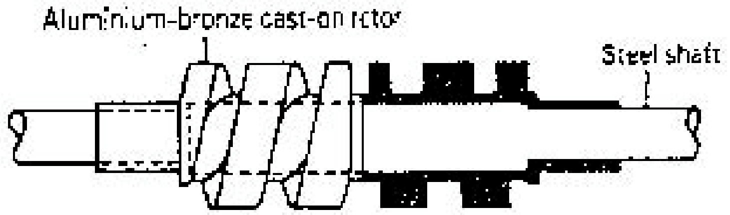
Because aluminium bronze sand castings are not normally prone to hot tears and contraction cracks, fillet radii do not need to be as large as in the case of steel castings, where large radii are recommended to avoid stress concentrations. Nor is it so necessary on aluminium-bronze castings to taper the junction of the body of a casting with a flange, as is recommended for steel castings, to avoid hot tears and contraction cracks. A slight taper may be desirable nevertheless for the reasons already mentioned.

The ductility of aluminium bronze at high temperature has pattern-making implication which will be dealt with in a later section.

Composite castings

The ductility of aluminium bronze at high temperature can be used to advantage in composite castings, that is to say casting where aluminium bronze is cast around another metallic component. An example of this is given in Fig 10, where an aluminium bronze rotor is cast on to a steel shaft. The rotor, being chilled cast, has enhanced strength, wear and corrosion resisting properties and the combination benefits from the higher strength of the wrought steel. In the latter stages of cooling, the aluminium bronze increases in tensile strength and exercises a powerful grip on the shaft. This principle can be applied to a variety of applications in order to take advantage of the respective properties of two metals: aluminium bronze providing its resistance to corrosion or its non-sparking property and steel giving strength and saving cost. This principle can also save machining cost where it is used instead of the conventional shrinking-on procedure.

Figure 10 – Half-section of a composite screw pump rotor



Differential contraction and distortion

At the instant of solidification of a casting there will inevitably be differences in the temperature between its various parts, due partly to differences in thickness and partly to the top of the casting, as cast, being hotter than the bottom.

Those parts of the casting at the higher temperature will want to contract more than the cooler parts. This differential contraction effect gives rise to internal stresses which are normally relieved if the casting is allowed to cool in its mould for an adequate period of time. In the case of a long slender casting, however, this differential contraction can lead to distortion, particularly if the design is asymmetrical. This can sometimes be overcome by introducing a slight opposite bend in the pattern equipment.

Another effect which may contribute to the distortion of such castings is the differential contraction discussed in the preceding section arising from the ductility of aluminium bronze at high temperature in relation to the restraint imposed by the mould on contraction.

Although cases of distortion are relatively rare they should nevertheless be borne in mind by the designer.

Design of castings for other processes

The preceding notes and design recommendations have been produced with sand moulds in mind. Although the general principles outlined are valid whatever the mould material, some processes are less susceptible to shrinkage defects than sand casting and each process imposes its own constraints and limitations on design. It follows therefore that in the case of aluminium-bronze diecastings and of castings produced in shell or in ceramic moulds, consultation with a founder who specialises in these processes is essential. The same is true of centrifugally-cast aluminium bronze.

Patterns

A casting can only be as good as the pattern it is made from. The care applied to the design of a casting must be matched by an equal care in planning and making the pattern equipment. It must be made to suit the pouring technique which the design should already have taken into account. It is vitally important that the founder should be consulted before patterns are ordered. The most convenient way of making a pattern may be totally unsuited to the production of a sound aluminium-bronze casting. A typical example is the pump casing shown in Fig 11.

The conventional way of making the pattern for such a casting is to split it along its axis of symmetry. This means that the awkward-shaped joint flange shown lies vertically in the mould. It simply is not possible with a short freezing range alloy such as aluminium bronze, to achieve directional solidification in these circumstances. This flange should lie horizontally in the mould, where it can be adequately 'fed' as well as the adjoining parts of the casting.

In view of the high cost of pattern making, it is essential that a pattern be made right first time. It must be made to suit the best production technique and thus avoid the need for fundamental modifications or, in some cases, complete replacement. Pattern accuracy is vital, not only to achieve dimensional accuracy which is essential in its own right, but also because the directional solidification of the casting is critically dependent on thicknesses being as planned.

Special attention needs to be applied to the correct choice of contraction allowances. It has been previously explained that two characteristics of aluminium bronze will singly or jointly cause differences in contraction according to wall thickness and to the restraining effect of the sand. These characteristics are the ductility of aluminium bronze at high temperature and the tendency of thin sections to contract less than thick sections. The bigger the casting the greater the need to assess the likely effect on contraction of these characteristics acting on the configuration of a particular casting. It is unwise to follow the common patternmaking practice of using a constant contraction allowance. Fig 12 gives linear contraction allowances for different casting thicknesses which do not however take account of the possible restraining action of the sand referred to. Variations in contraction are most prevalent on large castings and the advice of the experienced founder must be sought in such cases. It should also be noted that the technique of foundry production greatly affects variations in contraction.

Figure 11 – Centrifugal pump casing ***in nickel-aluminium bronze***

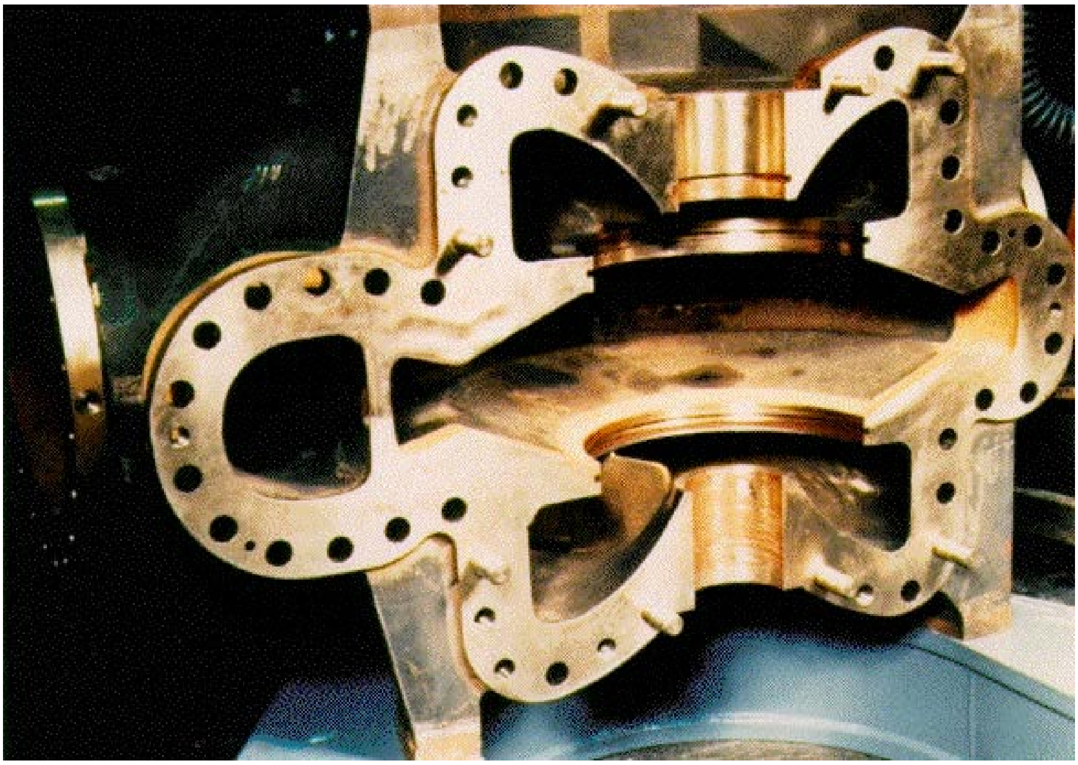
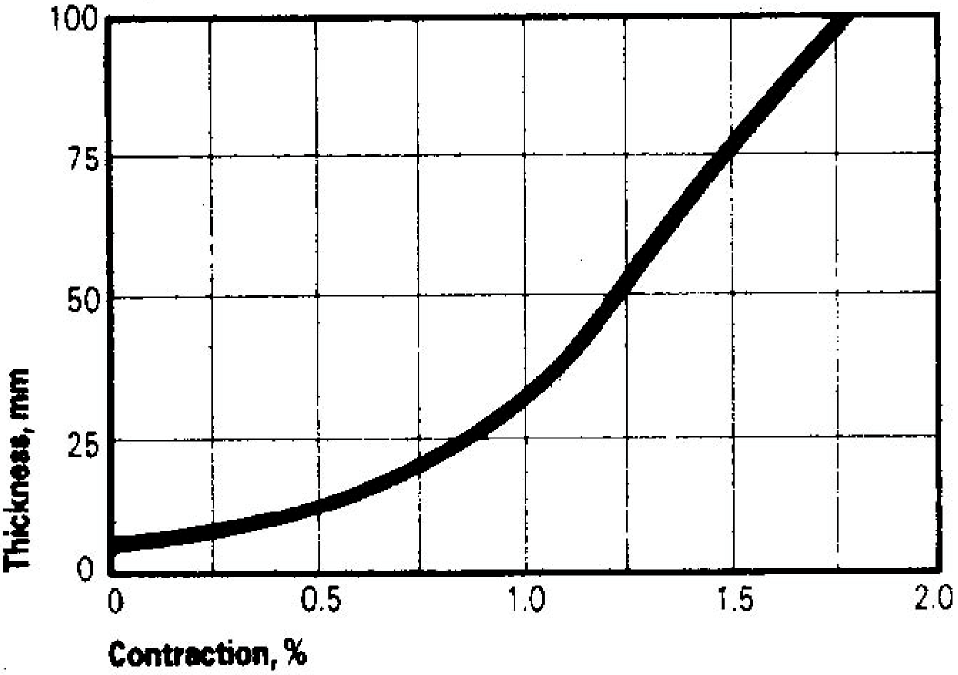


Figure 12 - Contraction in casting of different thickness



Quality - testing and inspection

The quality of a casting is crucial to its correct performance in service. A casting which is defective can have some or all of its supposed properties considerabiy reduced and poor performance in service may result. It is therefore essential for the user to specify his requirements at the outset and to co-operate with the chosen founder, if necessary, in developing a casting design to permit the achievement of the required quality.

At the same time, user and founder should agree on the methods of testing and inspection to be applied and on the standards of acceptance. It is important that these shall be adequate but also most important not to over-specify.

Some or any of the following methods of testing may be selected according to the needs of the application.

Analysis of alloy composition

All good foundries analyse their melts so as to ensure that the elements are present in the specified proportions. It is important that the analysis is carried out on the melt and is not the analysis of the ingots used since when ingots are re-melted a small proportion of aluminium in the alloys is lost due to oxidation and this can make a significant difference to the properties.

Mechanical testing

That the elements shown as being present in the correct proportions by the analysis are properly alloyed in the melt is demonstrated by a satisfactory mechanical test. This is the purpose of the test. It does not indicate the properties in the various parts of the casting, which will depend on the section thickness and rates of cooling and solidification.

It should a!so be noted that a satisfactory result from a sound test bar does not prove a casting to be free of defects. It is a reasonable assurance of metallurgical quality only.

Visual inspection

In addition to dimensional checking of a first, or all production castings according to need visual examination may be the only inspection specified or it may be just the first stage of the inspection procedure If visual inspection suggests that there may be defects present, the situation can be investigated by other means in more detail.

Penetrant-dye testing

This is a very satisfactorv method of detecting the kind of defects which may lead to a casting leaking on pressure test since it detects defects that come to the surface. Because of the tough skin of aluminium oxide formed on the surface of the casting, there is little tendency to metal mould reaction, if correct foundry practice is observed. There are therefore few misleading penetrant-dye indications and real defects show up clearly.

It is an advantage to carry out a penetrant-dye test even if the casting has been radiographed since there are areas of a casting which are difficult to radiograph effectively due to changes of section.

Radiography

Although expensive to use, radiography is a very effective method of detecting defects in aluminium-bronze castings. Because of the inherently compact nature of the alloy, the smallest cavity and inclusions show up clearly on films provided correct radiographic techniques are used. Because it provides a record of the nature and extent of the defects it is an invaluable tool for the experienced founder to use to develop his techniques for a particular casting, radiography should, however; be specified only when essential, and the number of shots and acceptance standards should be related to the realistic demands of the application if costs are to be kept within reasonable bounds.

Ultrasonic testing.

Because of its efficacy in determining the quality of chill cast aluminium bronze ultrasonics is also used to check diecastings and castings produced by centrifugal and continuous-casting processes. It is also invaluable for measuring section thicknesses of sand castings. Because of grain size it is not considered satisfactory, however for detecting defects in sandcast aluminium bronze.

Proof machining

This can be an expensive method of ensuring the soundness of a casting but is usually a necessary prelude to pressure testing. It is wise to combine it also with dye penetrant testing since proof machining may uncover defects not visibie to the naked eye and which penetrant-dye testing may reveal.

One advantage of proof machining is that weld rectification at this stage is quite possible, whereas it is often impossible to rectify a finished machined casting because of the danger of distortion.

Pressure testing

This is an obviously desirable test for all parts required to withstand pressure. It may be called for on all production or only or a percentage, according to experience with a particular design. It should be carried out at the earliest possible stage in machining so as to permit rectification by welding with the minimum of inconvenience and risk of ultimate loss due to distortion.

Rectification

One of the attractive features of aluminium bronze is that it is weldable. It is therefore usually possible to repair defective or damaged castings or to rectify machining errors by welding. This is far more satisfactory than impregnation since welding restores the integrity of the casting.

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