The manufacture of aluminium-bronze castings

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SYNOPSIS

Employing practices and equipment generally available for copper alloy castings like gun metals and phosphor-bronze, attempts have been made by Indian foundries to manufacture aluminium-bronze castings without understanding its basic principles. The paper has tried to deal with factors that should be considered for economic production of aluminium-bronze castings.

Briefly explaining the metallurgy of the alloy, the parameters governing foundry practice of aluminium-bronze have been discussed. Factors like the effect of short freezing range, structure, effect of casting and mould variables on mechanical properties, control of composition and gas absorption, etc. are explained.

Concluding, suggestions have been made to adopt such techniques that would give a sound casting.

THE development of aluminium-bronze alloys has basically been due to a combination of useful properties particuarly appealing to the designers in various engineering fields, the most important application being in the marine and hydraulic field. Important properties of aluminium-bronzes include the following:

(1) Useful combination of mechanical properties with ability to retain these properties at moderately elevated temperature:
(2) Excellent resistance to corrosion and cavitation erosion;
(3) High impact value; and
(4) High wear resistance.

In the design of castings, weight plays an important part both from the economical and functional points of view and castings of aluminium-bronzes have fulfilled these requirements admirably. Perhaps this is the only alloy in the copper alloy series where almost 80% of the test bar strength can be achieved in castings.

Although the properties of aluminium-bronze have been known for a long time, the use of the alloy in various fields-have not been appreciable but followed closely improvements in its casting and fabrication techniques. Castings of aluminium-bronze are generally employed as components of pumps, valves for water and steam, gear wheels, helical gearings of certain type, chemical and marine fittings and in food industries. Of the two principal alloys available, the AB-1 type of alloy containing nominally 10% Al and 2·5% Fe is used now mostly for die-casting. Bulk of the sand castings are made from the second AB-2 alloy, which has a similar aluminium content but with additional quantities of 5% each of nickel and iron. This alloy with slight compositional modifications is used in the manufacture of marine propellers, water turbine runners, pelton wheels, impellers and in many applications where resistance to cavitation erosion is important. Resistance to pickling by sulphuric acid led to its use in pickling hooks, chains, etc.

Although the alloy was available for casting purposes for many years, the difficulties involved in economic production of the alloy, free from casting defects, severely restricted its rapid development. Specific knowledge of the alloy through experience is lacking and there is not much published literature for the guidance of the founder. It is imperative that attempts in casting of this alloy will require considerable experimental work and therefore due allowance should be made for lapses until complete confidence is obtained for the manufacture of defect-free castings.

The main bottleneck in the growth of the aluminium-bronze industry was due to lack of understanding of the alloy. Metallurgically the alloy was treated in the manner of standard brasses and bronzes and economically it was considered unfavourable compared to brass and steel. A better evaluation of the casting problems of the alloy can be made when the metallurgical principles involved are properly understood.

Theoretical considerations

The problem of manufacture of aluminium-bronze casting is generally associated with lack of adequate technical and foundry control of the process particularly in the case of complex design and when service conditions are severe. Compared to the more common foundry alloys like gun metals and phosphor-bronzes, the aluminium-bronze has different metallurgical characteristics. A foundry, well conversant with manufacture of gun metal castings, will therefore be ill-advised to attempt aluminium-bronze castings in a

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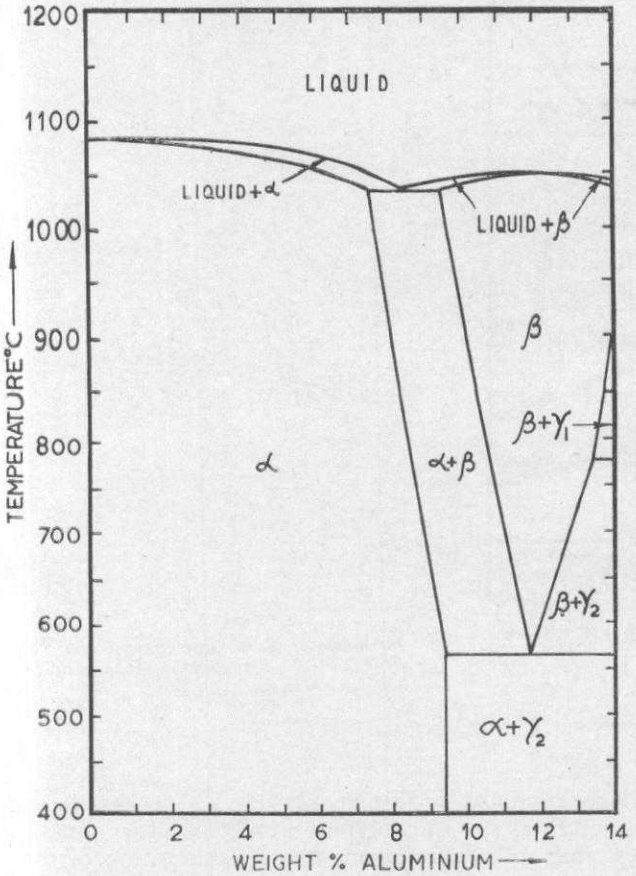


1 *Simplified copper-aluminium equilibrium diagram*

similar manner, without understanding certain metallurgical concepts of the alloy.

Aluminium-bronze alloys can be categorized in three distinct series as can be seen from the binary equilibrium diagram of copper-aluminium system. They constitute the α series, the $\alpha+\beta$ series and $\alpha+\gamma_2$ series, possessing properties entirely different in nature. The wide range of properties that can be obtained by suitable alloying addition and heat treatment has opened out immense possibilities for its application in various engineering fields. In fact, the role of aluminium has been compared with that of carbon in steel and comparison of properties that can be obtained with aluminium bronze has often been made.[1]

The α aluminium-bronze mostly in the solid solution range contains about 9·4% aluminium, which can be obtained in casting only on very slow cooling. It is difficult to avoid the hard β formation under normal conditions of cooling, even with 7·4% aluminium in the alloy. From the equilibrium diagram, Fig. 1, it is clear that the β structure is stable only at high temperature and undergoes an $\alpha+\gamma_2$ transformation at about 565°C. Being a sluggish process, it is not possible for the reaction to take place in castings undergoing normal cooling rate.

The β phase gives a high hardness combined with relatively high mechanical properties under normal conditions, but severity of cooling results in the formation of β phase with martensitic structure which has lower elongation. The α/β alloys have favourable combination of strength and corrosion resistance. The eutectoid structure of $\alpha+\gamma_2$, which has a lower electrochemical potential corrodes at a higher rate and has therefore to be avoided.[2] The decomposition of β to $\alpha+\gamma_2$, which occurs during slow cooling or reheating in the temperature range between 550°C and 350°C, has to be avoided. Cooling rates have therefore to be drastic.

The most important aspect is the eutectoid transformation in which the phases are;

1. α Al bronze having f. c. c. lattice similar to iron in its working characteristics.
2. β Al bronze with a b. c. c. structure.
3. β Al bronze which at the eutectoid transformation of 525°C transforms to $\alpha+\gamma_2$.

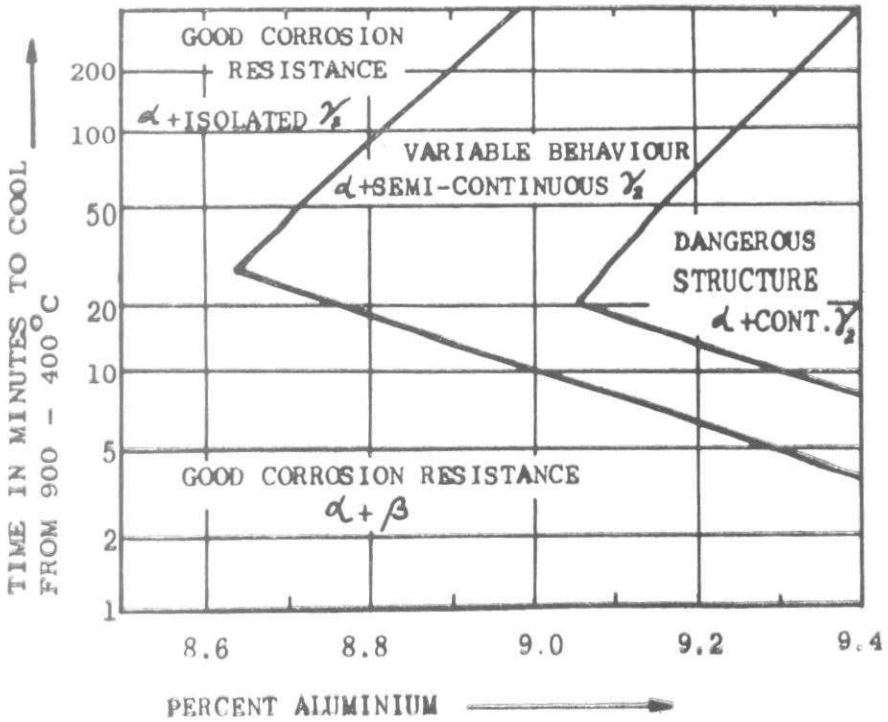
Role of added elements

The role of alloying elements like nickel, iron and manganese which tend to stabilize β and effectively permit slower cooling rate, is very important. When iron and nickel are present at a nominal level of 5% each, they modify the structure of aluminium-bronze and instead of the normal $\alpha+\beta$ an $\alpha+\kappa$ structure with small but tolerable amounts of β is formed. The complex alloys—notable for their high strength, corrosion and erosion resistance—can be cast easily without the influence of the eutectoid structure. This is the main reason that where die-casting is intended, the economical AB-1 type of alloy is preferred. In case of complicated sand casting where requisite mechanical and other properties like corrosion are important and desirable, the choice is of the AB-2 type of alloy, even though it may be an expensive product. In order to understand the role of alloying additions a knowledge of the effect of each of the elements is required.

Aluminium

Commercial binary alloys of aluminium-bronze usually contain about 8% Al, but the best combination of properties are obtained in the range of 9 to 11% Al. In this range of binary aluminium, advantage can be taken of the characteristic eutectoid transformation in which phase changes occur. This is very important in respect of engineering alloys where suitable heat treatment can confer desired properties in castings.

The α aluminium-bronze having an f. c. c. structure is suitable for such application where high corrosion resistance is important. The aluminium-bronze with a b. c. c. structure rarely exists by itself as a phase, but appears as a duplex α/β structure which confers a combination of properties like corrosion resistance and strength. At 575°C β transforms to $\alpha+\gamma_2$, like gamma brass. It is important to stabilize β to avoid complete formation of γ_2 as its formation leads to corrosion at higher rates. The effect of aluminium content and cooling rate on corrosion resistance of



2 *Influence of aluminium content and cooling rate on the corrosion resistance of binary copper-aluminium alloys*

binary aluminium is shown in Fig. 2[3] which clearly indicates the conditions to obtain acceptable structure.

Iron

The addition of about 1% iron improves the mechanical properties mainly due to its effect on grain refinement. Although additions up to 5·5% of iron is permitted, the influence of additions above 1·2% does reflect appreciably improved mechanical properties like tensile strength and hardness but lowered ductility. Iron also stabilizes β to some extent.

When iron is present in traces, it is not termed as an impurity but as a useful addition. Beyond 1% it is present as a finely dispersed phase in the structure and has no adverse influence on corrosion properties. It is possible to increase the solubility of iron in the solid solubility range by the addition of nickel.

Nickel

The addition of nickel has a strong influence in the stabilization of β. The α/β structure is retained at very low cooling rates even with 2 per cent nickel.

The addition of nickel to an alloy containing iron has a beneficial effect in modifying the stable structure. The γ_2 formation is suppressed and the α solid solution range is extended towards higher aluminium contents. Studies made with quaternary high strength alloys indicate a shifting of γ_2 phase progressively for various iron and nickel contents[4] (Fig. 3).

In an alloy nominally containing 10% Al, 5% Fe, 5% Ni and balance copper, the lower limit of eutectoid is found to occur at 11% aluminium and therefore γ_2 phase does not exit. The combined effect of iron and nickel produces a Kappa phase[4], which has the same structure as the β aluminium bronze. In alloys containing less than 11% aluminium, the decomposition of β produces $\alpha+\kappa$, when nickel and iron are also present. The size and disposition of Kappa can be controlled from fairly massive to fairly dispersed forms. By regulating the speed of cooling the transformation of $\beta \rightarrow \alpha+\kappa$ can then be arranged to obtain two very important effects—(1) hardening by precipitation (of κ in α) and (2) simple martensitic straining to obtain relatively softer phase (β decomposed to α).

In making castings having nickel and iron it is important to see that differential structures are avoided, as indeed should be the case when complex castings are attempted.

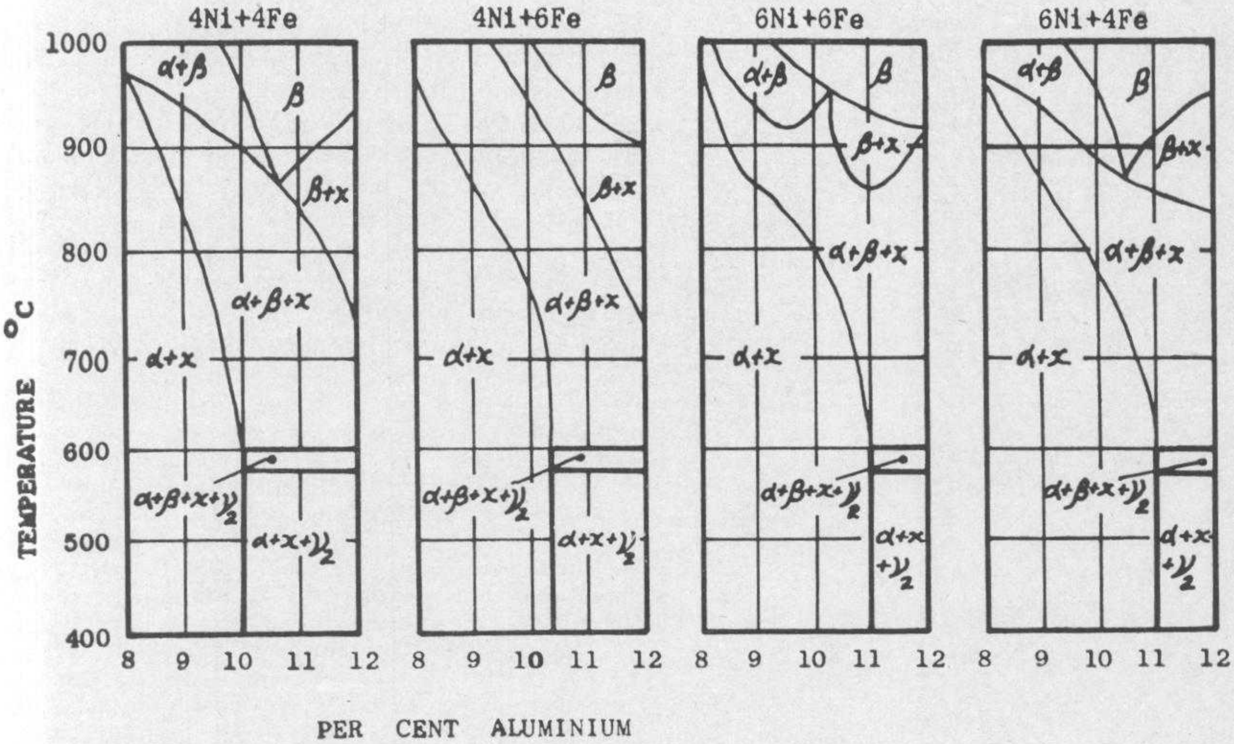
Manganese

The most important effect of manganese is in improving the corrosion resistance of the aluminium-bronze as it stabilizes the β phase and reduces the risk of decomposition of eutectoid. The stabilization of β can be achieved with low addition of manganese and additions up to 6% are sufficient to retain α/β structure at the usual cooling rates, met with in actual practice.

The main drawback, however, is that aluminium-bronze with a low manganese addition is susceptible to corrosion. When the addition exceeds 11% a fully stable α/β structure is obtained resulting in improved corrosion property of the product.

Physical parameters

In handling aluminium-bronze at melting and casting stage, it is important to consider factors which control



3 *Equilibrium diagrams of the quaternary system Cu-Al-Fe-Ni*

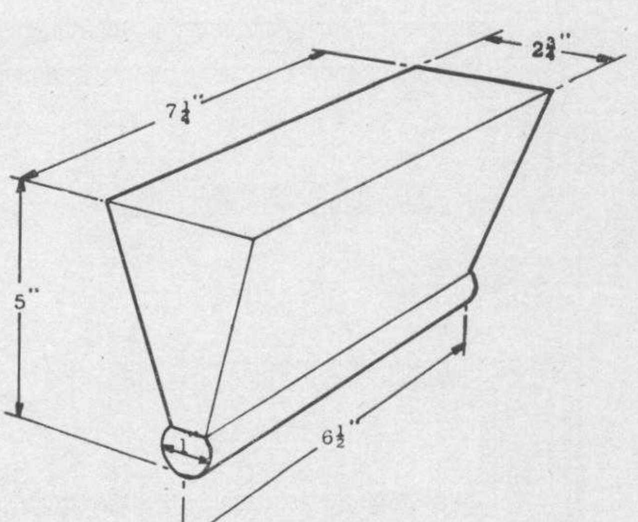
production of (1) clean metal, (2) permit ease of casting without undue metal loss, (3) control mould design that would permit a clean and solid casting with minimum feeder head, riser head loss, etc. and (4) finally allow minimum post casting treatment. The above can be achieved with proper control at each stage of working and mainly depends on factors like control in metal store, control in metal quality, control in mould making materials and finally control in pouring, running and feeding techniques. It may not be justifiably possible to deal with all the above factors in a restricted review like this but the most important ones will be dealt in this paper.

The principles of application of control in metal store are well understood and irrespective of the metal handled a well known procedure is available and can be adopted. In case of control of melt quality special precautions have to be taken for all the copper alloys, more so for aluminium-bronze, for the production of casting to be economic with consistency in quality. To ascertain that melt quality conforms to requirements it may be necessary to check microstructure and dissolved gas of the alloy along with compositional check, to ensure that resulting casting will be of requisite quality.

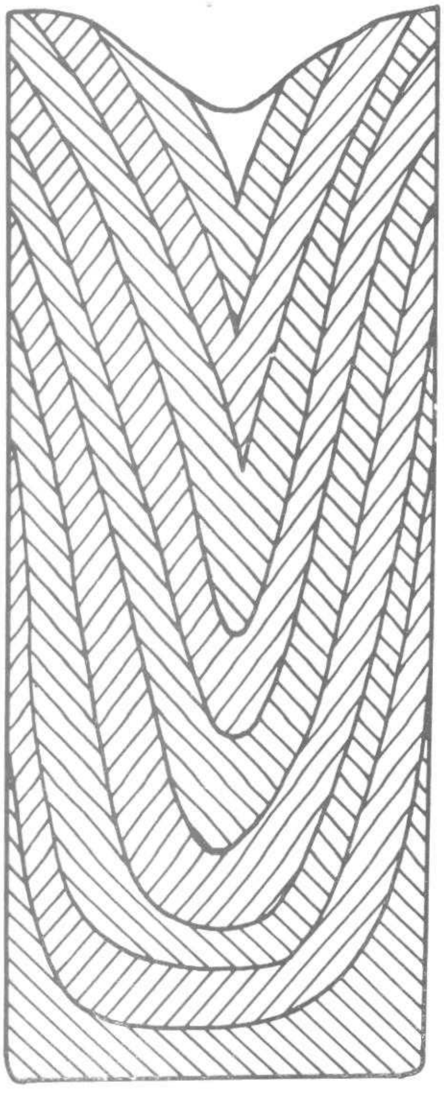
The most common and rapid control tests are the fracture and density tests determined by the usual modified DTD type test bar—in case of aluminium bronze, a separate specimen has to be cast for tensile test. This is generally a keel bar designed and cast as per dimension given in Fig. 4.[5] It would be an advantage to use inert mould materials to avoid the possibility of any gas pick-up that might affect the soundness of the casting.

Melting and casting variables

It is necessary to understand the characteristics of the



4 *Recommended dimensions for a keel bar casting for the production of aluminium bronze test bars*

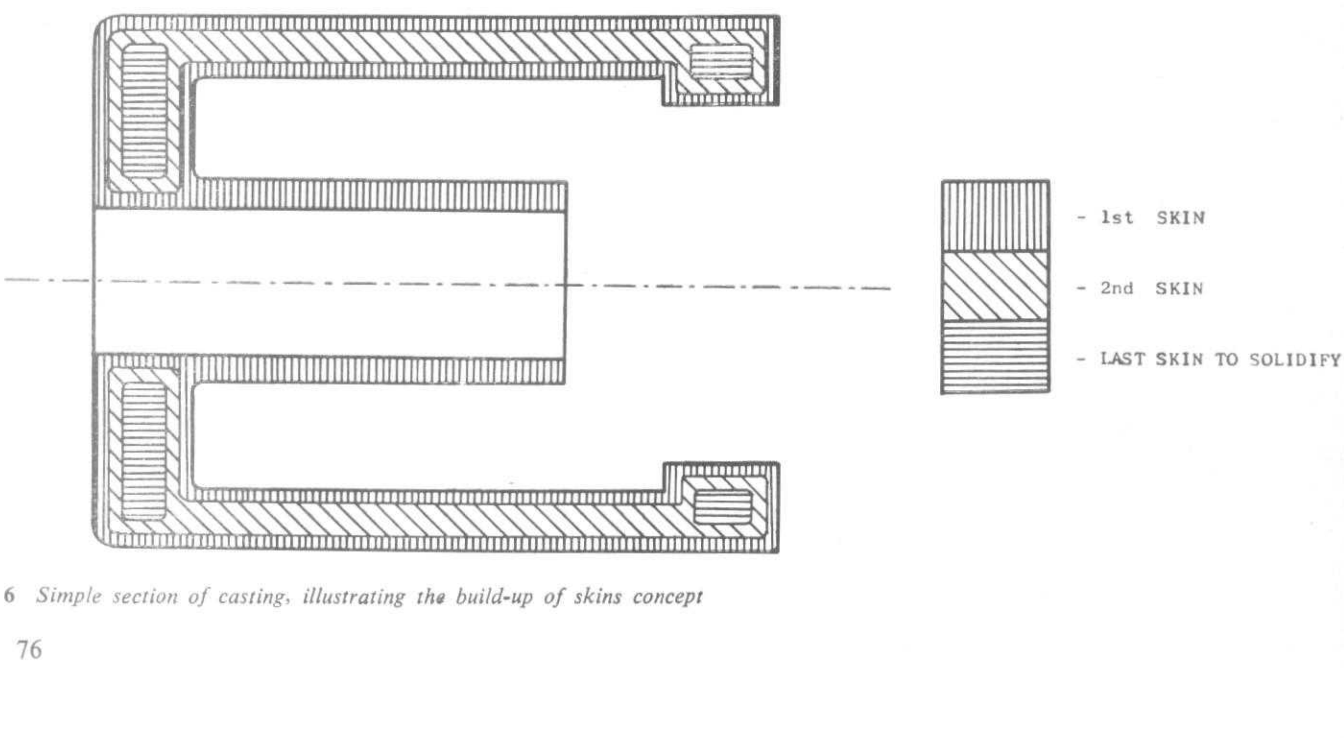


5 *Pattern of solidification in a casting of aluminium bronze*

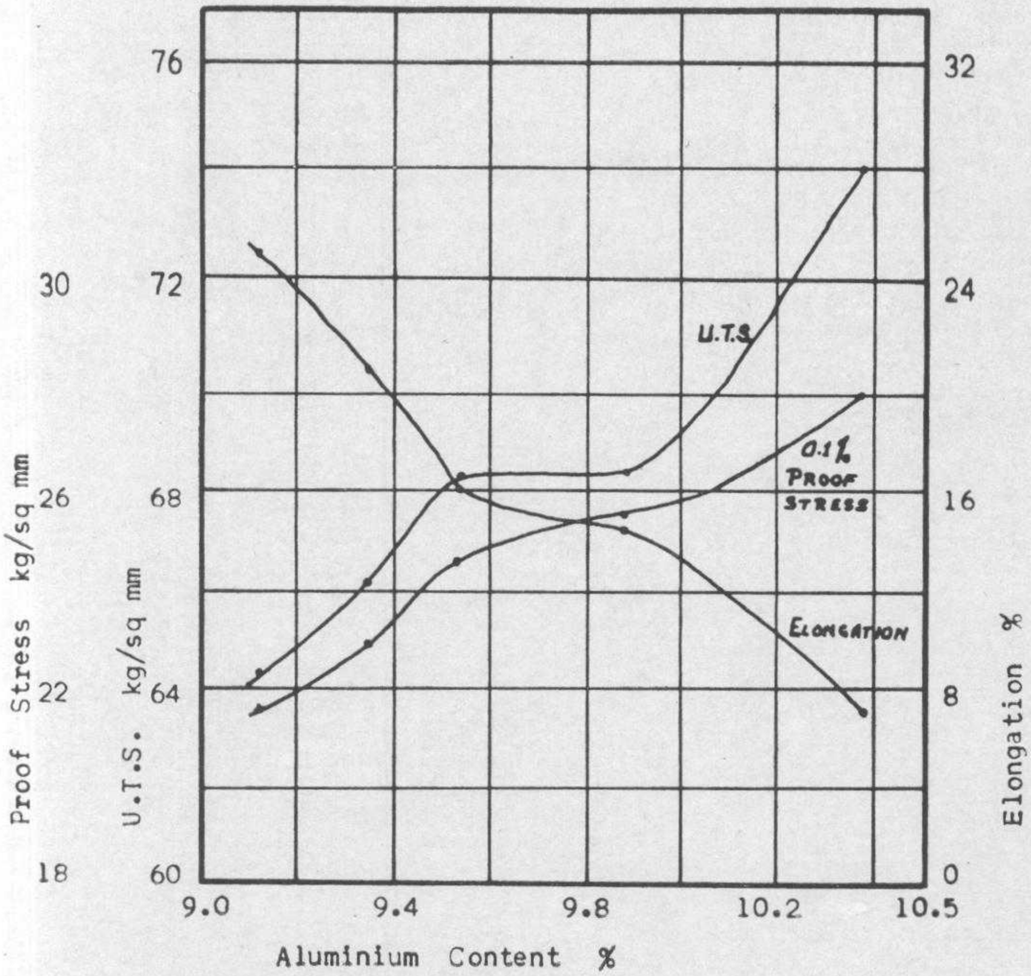
alloy and the correct melting technique to obtain clean metal without much of slag formation. The high aluminium content results in dross formation during melting which should be limited to avoid loss of aluminium and contamination of the melt. Melting variables should be controlled to keep the turbulence of metal as low as possible so as to avoid dross formation and mix up which eventually might get entrapped in solidifying metal. The formation of oxide film can in many cases be advantageous but generally results in compositional changes due to loss in aluminium. Once formed and if not disturbed, it prevents further oxidation of the melt. A steady pouring of metal into the mould will maintain the outer skin of oxide acting as a pipe through which the metal can flow. The oxide skin formed at metal/mould interface lessens the chance of mould reaction to give a better surface finish.

The fluidity of metal is another factor for avoiding dross entrapment. This is possible when the metal has sufficient superheat so that the dross can rise to the surface into the risers during casting operations. It is not possible for the metal to be in such a condition in very thin castings and dross entrapments do occur, resulting in heavy machining of the parts.

The aluminium-bronzes have a low freezing range and liquid to solid transformation can occur over a low range—as low as 10°C—with a marked volume shrinkage, resulting in cavities and other related defects. It is, therefore, important to control both the solidification and the volume of the feed material. The prime effect of low freezing range is that the metal solidifies mostly as a pure metal in successive layers in the form of skin as shown schematically in Fig. 5. This should result in a sound casting, but the last portion to solidify suffers the shrinkage effect and results in piping and shrinkage cavities, as shown schematically in Fig. 6 for a simple shape. Generous



6 *Simple section of casting, illustrating the build-up of skins concept*



7 *Effect of variation in aluminium content on mechanical properties of an aluminium bronze under constant casting conditions (Ni 4·64–4·71%, Fe 4·15–4·20%)*

feeding and risering effect will have to be maintained to overcome the effect.

Control of composition

Control in composition is generally difficult when virgin charge is employed compared to melting of standard alloy ingots. This is mainly because the loss of aluminium cannot be determined consistently due to the deoxidising power of aluminium when virgin metal is melted. Even charcoal is not helpful in avoiding loss of aluminium when the virgin copper is melted initially.

The need for control of composition has arisen from the fact that the tensile properties are altered by changes in the aluminium content. Crofts and Bates[6] have shown that the strength of test bars of complex aluminium-bronze is influenced by changes in aluminium content while the proof stress can be increased by increasing the nickel content. Significant effects due to changes in the addition of other elements have also been reported by Cook, Fentiman and Davis.[4] Excessive loss of aluminium from the melt should never be permitted because variation in aluminium content leads to the attainment of different mechanical properties as can be seen from Fig. 7.

All precautions taken during melting will be of no avail if the metal temperature prior to pouring into a mould is not controlled. Any variation of temperature in the hot metal will yield variation in the tensile properties of the castings. Experiments carried out by Wilson and Tull[7] demonstrate the mechanical properties of a complex aluminium-bronze as shown in Table I.

TABLE I Effect of variation in casting temperature on mechanical properties for an aluminium-bronze (9·8% Al, 4·56% Ni, 4·75% Fe)

Pouring temperature, °C	U. T. S. kg/sq. mm.	0·1% Proof stress kg/sq. mm.	Elongation % (50 mm gauge length)
1180	67·2	25·4	14
1150	68·5	25·4	15
1125	70·1	25·5	18

According to the authors, the above differences are due to improvement in grain size. The control of grain size does not seem to be a problem with complex alloys, when compared with binary alloys.

In the case of alloys which solidify in the β range first, mechanical properties via grain refinement can be achieved by the addition of boron to the melt. Results, reported by Dennison and Tull[8] as per Table II although

TABLE II Effect of grain refinement on mechanical properties of 9″ dia. billet of binary aluminium-bronze cast at constant pouring temperature

Nominal boron content %	Aluminium content %	Grain size	U.T.S. kg/sq. mm	Elongation % (25 mm gauge length)
0	9·50	Grains columnar 0·75 in. (19 mm)	36·9	18·4
0·01	9·39	Average grain diameter 0·05 in. (1·27 mm)	40·3	25·0
0·02	9·49	Average grain diameter 0·03 in. (0·76 mm)	41·6	26·3
0·03	9·42	Average grain diameter 0·03 in. (0·76 mm)	41·7	26·9

* Average of 6 results obtained from specimens taken from different areas of the billet including both transverse and longitudinal directions.

refer to 9″ dia. billet, are none the less indicative of the grain refinement and its relation to mechanical properties.

Melting units

Melting of aluminium-bronze does not pose a problem but depends largely on the type of equipment used. Generally the brass and bronze foundries are equipped with gas or oil fired crucible or reverberatory furnaces and it is possible to use these furnaces to advantage if proper furnace atmospheres are maintained. Probably the best melting conditions are obtained with low or high frequency induction furnaces. Investigational results indicate the extent of losses with different furnaces, as given in Table III.[9]

The most important point to be considered is the type of furnace atmosphere to be maintained during melting of aluminium-bronze, because of the peculiar characteristics exhibited by the metal. The reducing or oxiding furnace atmospheric conditions appear to work in direct opposition to each other. As noted earlier, the oxidising atmosphere tends to introduce variations in composition

TABLE III

Furnace	Cover	Melting loss %	
		Heavy charge	Light charge
1. H. F. Rocking Arc	Halide	3·2	—
2. Crucible	Halide	3·4	—
	None	4·3	9·4
3. Rotary	—	—	—
4. Reverberatory	Halide	4·3	—

due to drossing of aluminium. In case hydrogen atmosphere is inadvertently induced as in the case of poorer melting practice, the metal picks up hydrogen. Information available on the effect of hydrogen in aluminium-bronze is not conclusive but does indicate that only in fine grained material gas porosity can be avoided.

Gassing due to hydrogen can be avoided during melting in oil or gas fired furnace by maintaining slightly oxidising atmosphere. It appears therefore that the melting equipment plays an important part in balancing the effect of gas pick-up and the amount of drossing that can be tolerated. It is important that when using a reverberatory furnace with an open flame, consistently correct atmosphere should be maintained. Another factor that works against the use of reverberatory is that it allows a greater surface area of the molten metal for both effects to be equally predominant. For the manufacture of larger and heavier castings the use of reverberatory furnace is unavoidable, but in such cases rigid atmosphere control is necessary.

Furnace charge

A charge with a high surface area like machine shop turnings is likely to give high melting loss varying from 5 to 14% whereas a charge consisting of virgin metal, ingots or heavy sections alone yields a loss in the range of 1·5–5%. The first charge should be large solids so that turnings, etc. may be charged later to the bath of molten metal after initial melting down. To obtain a reasonable control of final composition when using foundry returns, the charge should consist of only 50% old materials. Pre-heating the charge may also prove beneficial.

Mixtures of fused metallic salts such as chlorides or flourides are preferred as flux covers for aluminium bronze metals as they have a superior solvent action on the dross. In many cases fluxless melting has been practised with equal success and yet in some cases only common salt has been used to advantage as a flux cover. In order to limit oxidation, addition of beryllium to the extent of 0·001–0·005% has been recommended[10] provided, the element is not present in the charge already.

Additions of nickel, iron and manganese are made in the form of master alloys. It is always advantageous to cast the metal first as pre-alloyed ingots and then remelt them for production of castings. This ensures not only better control over composition but also helps in avoiding hydrogen pick-up.

Moulding techniques

Moulding and casting techniques for aluminium bronze need special attention because of its low range of solidification and the tendency for dross formation. The latter will be predominant when turbulence during pouring of the metal occurs. Turbulence may also be due to mould material where hard rammed fine sand mould of low permeability is used. The sand with clay content of 12–17% having a permeability of 70 A. F. S. is most desirable for casting. In case of green sand the moisture content should not exceed 4% and should preferably be well below this figure. For larger shapes sand cement has been used with advantage but the use of mould dressing, particuarly those containing graphite, should be avoided.

Attention to chilling and risering helps to avoid shrinkage cavities and the gating should be such that metal turbulence in the mould should be a minimum. Use of chills either of cast iron or graphite is recommended to obtain directional solidification with complex castings. Where heavy and light sections join, chills are used to chill the light section directionally to the heavy section ensuring that heavy section is fed adequately with metal. Haphazard chill application can create problems and only experience can be the most judicious criterion.

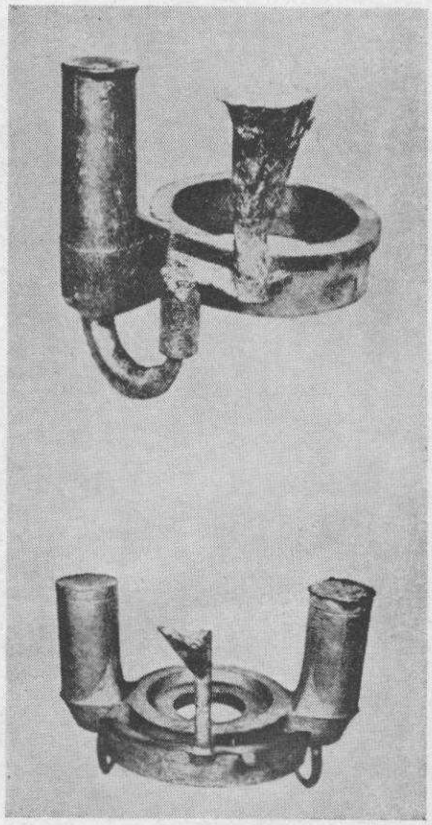
Gating and risering

Normal straight gates used in casting copper alloys cannot be used for aluminium-bronzes, because of turbulence causing heavy drossing during pouring. Generally, gating is applied wherever possible into the lowest level of casting, and in this context the height of the casting should be in the minimum position. Pouring basins are useful to avoid turbulent flow of metal into the sprue.

Feeding successfully into mould involves due consideration of sprue, runner and ingates and works experience has indicated that the ratio of their areas should be of the order 1 : 2 : 4. This coupled with strain gates, reverse horn gates, skim gates and step gates provide improved casting. Examples of the feeding systems of the casting are given in Figs. 8 and 9.

In case of small castings the weight of metal in feeding system may be more than the casting which cannot be avoided if sound castings are desired.

Depending on the size of work-piece the casting process is varied to suit individual items. Large bushings, deep rings or larger naval propellers are cast vertically with two reverse horn gates leading into the bottom of the casting at diametrically opposite points.



8 *Gating and feeding systems with horn gates*

A central sprue is attached to the runner bar with strainer cores and risers liberally applied. Heavy castings having irregular cross section are generally cast with a skim gate attached to reverse horn gate. Gear blanks which conform to this category has the riser placed directly in the centre hub of the casting and the large end of the horn gate leads into the hub.

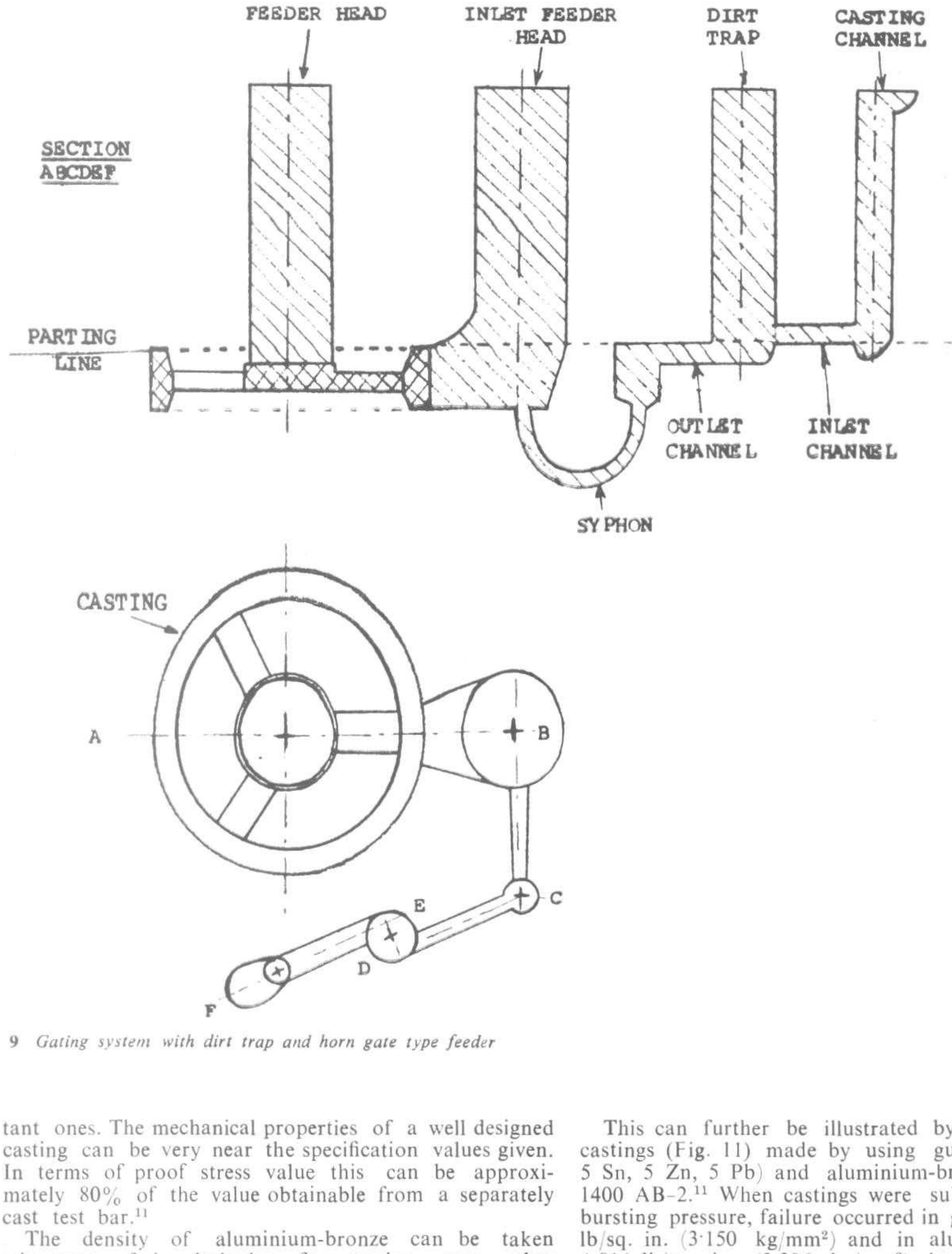
Castings like bushes are cast horizontally with a larger riser at one end and a skim gate attached to the reverse horn gate leading into the riser well.

For thin section it is not possible to use horn gates with feeder heads, but flat gates are provided with dross traps. The casting in such cases is ingated at multiple points. In the latest practice the use of horn gate has also been discontinued, except in the case of ingating for the metal to reach inaccessible regions of complex castings.

Under no circumstances, pouring of the metal into casting should be interrupted, and when pouring is completed it may be advantageous to cover all the risers with exothermic compounds.

Engineering design — parameters

Reproducibility of casting in aluminium-bronze is fairly easy when the design of the casting is satisfactory as also its casting technique. In designing a casting, a number of factors are considered, the ratio of strength/weight of the casting being one of the most impor-



9 *Gating system with dirt trap and horn gate type feeder*

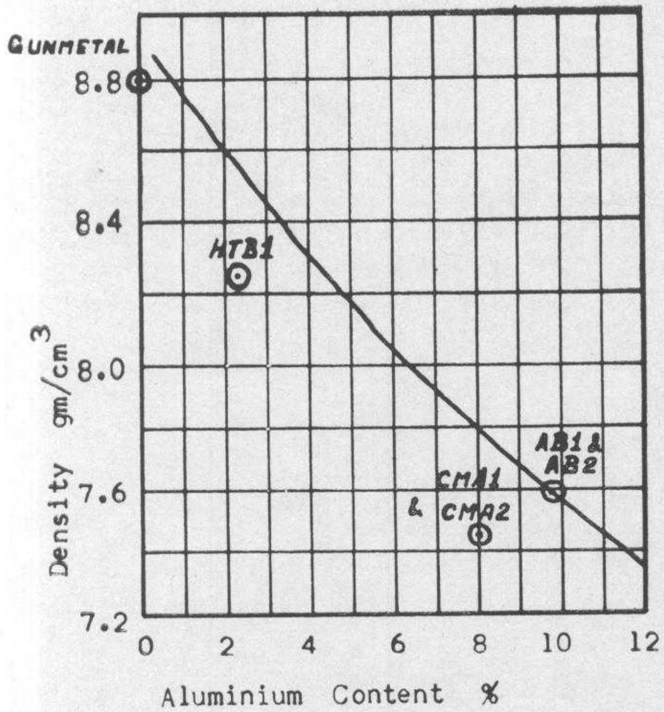
tant ones. The mechanical properties of a well designed casting can be very near the specification values given. In terms of proof stress value this can be approximately 80% of the value obtainable from a separately cast test bar.[11]

The density of aluminium-bronze can be taken advantage of in designing for casting, over other copper alloys. Where property requirements are comparable aluminium-bronze can be made to replace high tensile brass with an overall weight saving of approximately 8% using the same design in casting. In the case of gun metals, the replacement entails a saving of about 13% with improvements in design and mechanical strength of the castings. In Fig. 10[11] a comparison of densities has been made for some of the common alloys.

This can further be illustrated by two experimental castings (Fig. 11) made by using gun metal (85 Cu, 5 Sn, 5 Zn, 5 Pb) and aluminium-bronze as per BS: 1400 AB-2.[11] When castings were subjected to internal bursting pressure, failure occurred in gun metal at 4 480 lb/sq. in. (3·150 kg/mm^2) and in aluminium-bronze at 4 816 lb/sq. in. (3·386 kg/mm^2) in spite of the fact that the wall thickness of gun metal casting was two and a half times that of aluminium-bronze.

Surface finishes of the casting can be of high order and in many cases no hydroblasting may be necessary. Welding of casting can be successfully carried out by argon arc methods. A complex casting can be fabricated by joining multiple castings.

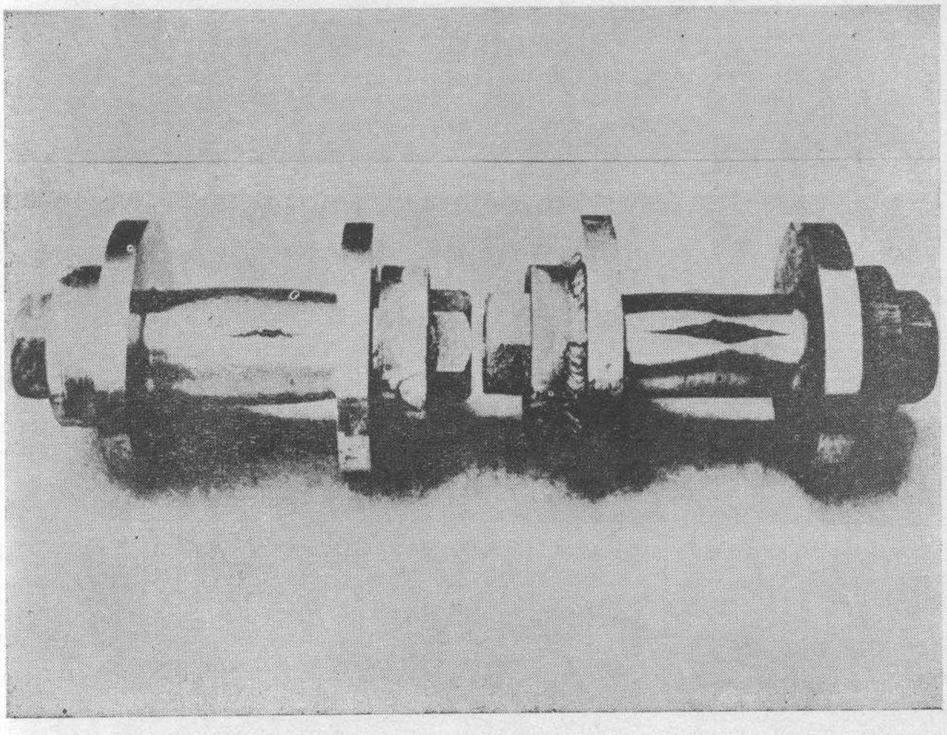
Co-ordination of the foundry technologist and the design engineer is essential to obtain high quality



10 *Relationship between aluminium content and density of copper-aluminium alloys*

TABLE IV Foundry defects attributable to poor design

Defect	Cause	Foundry remedy	Design remedy
1. Shrinkage cavities and surface sinks	Lack of sufficient feed metal	1. Feeder heads	1. Uniform thickness wherever possible
		2. Chills internal and external to rapidly cool isolated masses	2. Provide progressive and uniform variation of thickness
		3. Padding i. e. thickening of the casting from the feeder to the part to be fed	3. Minimise local accumulations of metal
			4. Modify wall junctions.
2. Blowholes	Occlusion of gas evolved from the mould	1. Venting to allow easier escape of evolved gases	1. Avoid sharp corners and re-entrant angles
		2. Modified sand mixes low in gas producing materials	2. Avoid very narrow cavities and use of cores which are difficult to vent
3. Misruns	Low metal fluidity	1. Very high casting temperatures and fast pouring	1. Avoid very thin sections which have a large surface area
		2. Modifications to running and gating system	



11 *Comparison of gunmetal and aluminium bronze castings*

castings in aluminium-bronze. It is important that the foundry has a prior knowledge of the service conditions and function of parts being cast. The design engineers should also be appraised of the possible defects that can creep in due to poor design. In Table IV a summary of general defects attributable to casting design is given.[12]

Conclusion

Aluminium-bronze castings have a potential role in the developing copper alloy foundry. The high strength, corrosion resistant alloys can be used advantageously in multiple applications and the useful properties should stimulate interest in its technology and application in a developing country like India.

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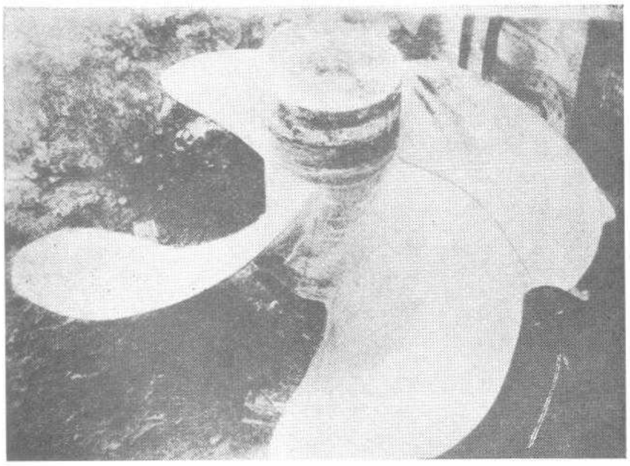
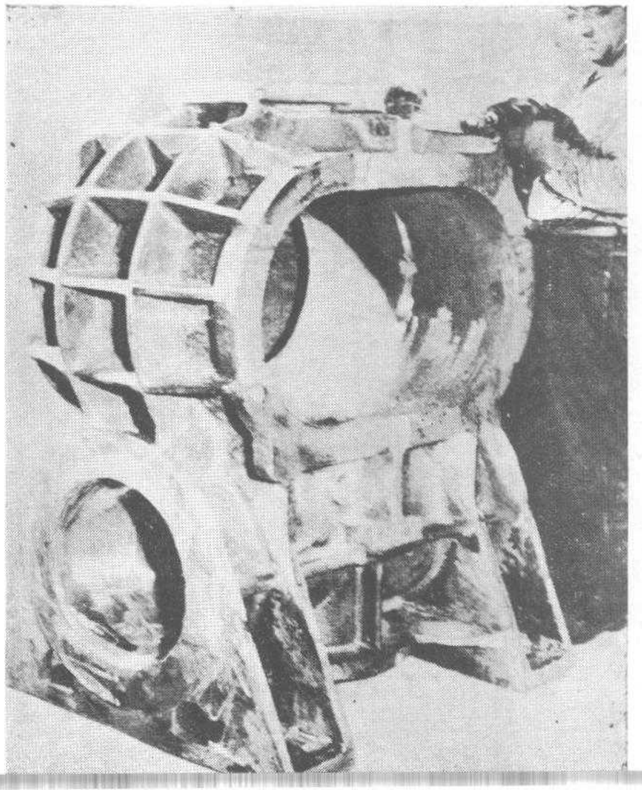
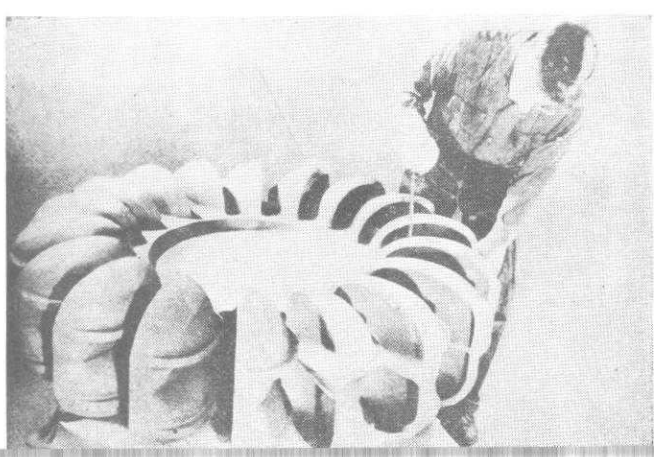
APPENDIX

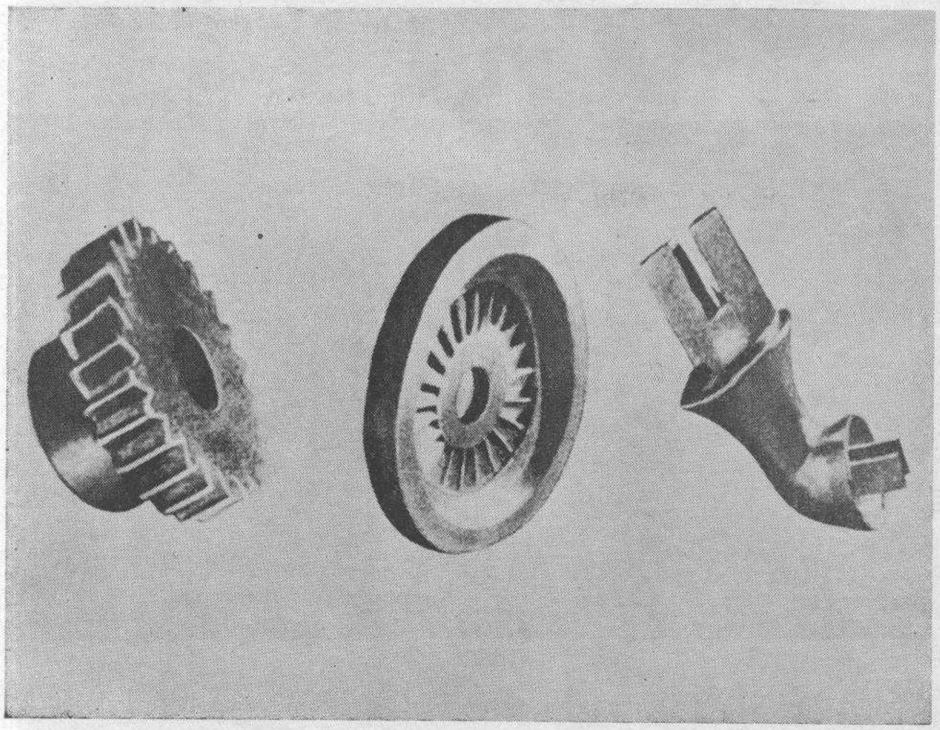
Some typical castings in aluminium bronze



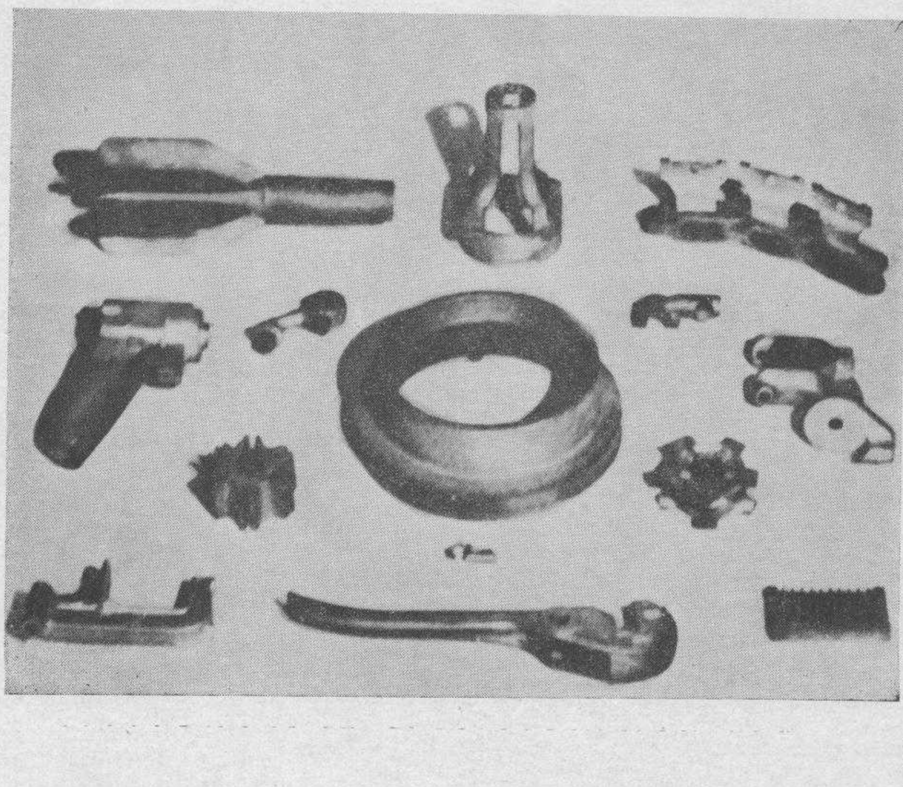
Sand castings







Chill and die castings



Discussions

Mr **V. P. Arya** (Hindustan Steel Ltd., Rourkela): The author has very correctly pointed out that graphite dressing is undesirable in aluminium-bronze castings. Which mould would the author suggest for these castings?

Mr **Man Mohan Singh** (Small Industries Service Institute, Ludhiana) : The author has stated that attempts have been made by the Indian foundries to manufacture Al-bronze castings. Factors like short freezing range, composition, gas absorption, blow holes, etc. can be controlled by the temperature of the metal. It is well known that rate of pouring, height of pouring, size and shape of runner and gates for different section thicknesses of casting, also play an important role in the technique of casting. Will the author give his suggestions on these factors with reference to Al-bronze castings?

Mr **Devendra Sahai** (Hindustan Steel Ltd., Bhilai) : Alloys which contain upwards of 11% of aluminium and therefore show greater quantities of the β or γ_2 phases, tend to possess extremely low ductility and high hardness. Some castings of alloys containing as much as 13·5% aluminium along with large amounts of other elements are used where considerable hardness is essential. I would like to know from the author what elements are added to overcome the shortcomings due to a large amount of aluminium and where these alloys are used.

I would also like to know which is the best deoxidant in the manufacture of aluminium-bronze?

Dr **L. R. Vaidyanath** (Author) : In reply to the question raised by Mr V. P. Arya, I would like to make a comment to modify the statement in regard to the use of graphite mould wash mentioned in my paper. Graphite as a mould wash was prohibited in certain Admiralty specifications and other castings where corrosion resistance is very important. It was feared that the presence of residual graphite particles on the surface of the casting might entail corrosion failure of the casting while in service at a later date. The views are now generally modified because the means of overcoming the presence of graphite are many, one of them being shot blasting of the cast product. Graphite, therefore, can be safely used where subsequent treatment like shot blasting, cleaning or any other efficient removal methods are employed.

With regard to the query raised by Mr Man Mohan Singh, I would like to mention that the answer is not very simple. It is very difficult to outline the process of casting including the height of pouring, size and shape of runner and gating techniques for different section thicknesses of casting. In the appendix, I had shown a photograph of the gating techniques for some bushes and gear wheels. It is necessary to study the size of the casting as well as its shape before one can establish the gating and risering techniques that affect the quality of the casting. It must be, however, emphasised here that because the aluminium-bronzes have very small freezing range, the solidification occurs the same way as in pure metal. This enables sounder castings to be obtained but the total shrinkage effect is concentrated in those regions of the casting that freeze last, thus making it susceptible to piping and gross shrinkage cavities. The feeders are, therefore, larger compared to gun metal and similar alloys.

The rate of pouring of course should be well controlled and the height of pouring should be kept to a minimum. In fact, it is known that metal forms a skin which acts as a 'pipe' through which the metal enters the mould cavity. The formation of 'pipe' helps to prevent any further oxide formation and should not be disturbed. Depending on the size of the castings, tilting method can be employed satisfactorily. Examples of running and gating are illustrated in some of the excellent publications like the one brought out by the Copper Development Association, London. It may be emphasised that no rigid method can be specified and initial experimentation may be necessary for a final successful technique. It is easier to deal with a specific problem than to generalize on the subject.

In reply to Mr Devendra Sahai, aluminium-bronzes containing 12 to 14% aluminium have exceptionally high hardness values accompanied by very low ductility. This is why the aluminium-bronzes containing high aluminium are used where the loading is fully compressive and are subjected to high wear rates. These alloys contain practically no alpha and they are susceptible to grain growth at high temperature. To some extent this is obviated by an addition of iron but the general property can be improved by further additions of tin. The addition is kept well below 1%. Nickel is normally not present in such alloys.

Alloys containing 11 to 11·5% aluminium with 5% nickel and 5% iron have been developed for applications where hardness values of 300 HV are important. There are some excellent papers on this subject and I would suggest the following references:

1. Dennison, J. P. and Tull, E. V. 'The Application of Grain Refinement to Cast Copper-Aluminium Alloys containing the β phase', J. Inst. Met., 1951–52, 80, 419–29.

2. Goel, D. B. and Saxena, M. N. 'Commercial Utilisation of Aluminium-Bronzes', The Eastern Metals Review, Mid-year Number, 1967.

In regard to the best deoxidant in the manufacture of aluminium-bronze, it is well known that aluminium itself is a very good deoxidiser. The question is not quite specific. If it is intended to use virgin metals for the manufacture of aluminium-bronze, then the copper has to be deoxidised before aluminium additions are made. This can be done in a conventional manner, if aluminium is not to be lost by dross formation. Alternatively, if standard alloy ingots are used for melting, it is better to melt these alloys under natural cryolite cover so as to prevent excessive dross formation.

Mr **R. D. Gupta** (National Metallurgical Laboratory) : Extensive work has been done at the NML on chill cast aluminium-bronze alloys. The effect of a few drops of carbon tetrachloride in the chill mould prior to casting and mould dressing of 50 : 50 saturated solution of sodium chloride and potassium chloride showed great improvement in the surface finish of the casting and passivity of the ingot ; this might be attributed to the replacement of air by the gases evolved from the carbon tetrachloride and/or chloride dressing.