BIBLIOGRAPHY.

Anderson, Sir Wm., "Fourth Report Alloys Research Committee," *Inst. Mech. Eng.*, 1897.
Baker, *Phil. Trans.*, vol. cxcvi. p. 529.
Bengough and **Hudson**, *Jour. Soc. Chem. Ind.*, January 1908.
Charpy, *Bulletin de la Société d'Encouragement*, "Contributions à l'étude des Alliages."
Herschkowitsch, *Zeitschrift für physikalische Chemie*, vol. xxvii. (1898), p. 123.
Le Chatelier, A., *Revue générale des Sciences*, 1891 ; *Comptes Rendus*, 1890.
Le Chatelier, H., *Contributions à l'étude des Alliages.*
Macklin, *The Brasses of England.*
Roberts-Austen and **Stansfield**, "Fourth Report Alloys Research Committee," *Inst. Mech. Eng.*, 1897.
Shepherd, *Jour. Phys. Chem.*, 1904.
Sperry, *Jour. Amer. Inst. Min. Eng.*, July 1897, February 1898, October 1898.

CHAPTER IX.

COPPER ALLOYS. SPECIAL BRONZES AND BRASSES.

Phosphor-bronze.

THE addition of phosphorus to bronze has usually been attributed to Dr Künzel of Dresden, but it appears that De Ruolz and De Fontenay had carried out experiments on the introduction of phosphorus into bronze as early as 1853.

Phosphorus unites both with copper and tin, forming the alloys known as *phosphor-copper* and *phosphor-tin*; and as these products are used as the means of introducing the phosphorus into bronze, they may be briefly considered.

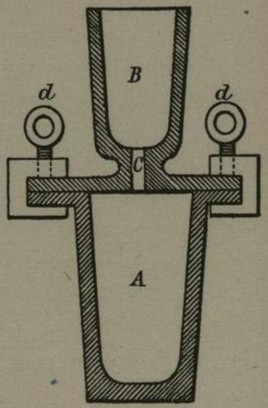

FIG. 31.—Phosphor-copper Crucible.

Phosphor-copper may be prepared in a variety of ways by reducing phosphates in presence of copper; but it is usually prepared by direct combination of copper with phosphorus.

Hiorns describes an ingenious apparatus for the manufacture of phosphor-copper and phosphor-tin, which is shown in fig. 31.

Phosphorus is placed in the lower vessel A, and the molten metal is poured in through the upper vessel B. Any phosphorus vapour which escapes combination in the lower vessel is caught as it passes through the molten metal in the upper vessel.

When phosphorus is added to copper the colour rapidly changes until the alloy contains 15 per cent. of phosphorus, when it is blue-grey in colour, very hard, and brittle. It is, in fact, a definite phosphide of copper Cu_3P (or Cu_6P_2). This compound alloys with copper in all proportions, forming a series whose freezing-point curve belongs to the first type. The eutectic contains about 10 per cent. of phosphorus, and melts at 700°.

The alloys sold commercially as phosphor-copper usually contain 10 and 15 per cent. of phosphorus.

Phosphor-tin is prepared in the same manner as phosphor-copper. The commercial alloy, which usually contains about 10 per cent. of phosphorus, is brittle and beautifully crystalline.

The action of phosphorus on copper or bronze is a double one. In the first place, as is well known, phosphorus has a powerful affinity for oxygen, and when it is added in the form of phosphor-copper or phosphor-tin to the molten metal, its first action is to reduce any oxides which may be present. The oxide of phosphorus thus formed has an acid character and combines with a further quantity of metallic oxides forming phosphates, which pass into the slag.

The bronze, which is now free from the dissolved oxides which cause so much trouble, is more fluid, gives castings free from pinholes, and is superior in every way to ordinary bronze.

If the quantity of phosphorus has been accurately judged, none of it will pass into the bronze; and this accounts for the fact that many excellent bronzes sold as phosphor-bronzes have failed to show the presence of phosphorus when submitted to chemical analysis. Their superiority over bronzes produced without the addition of phosphorus is entirely due to the removal of dissolved oxides.

The value of phosphorus as a deoxidiser is now fully appreciated, with the result that its importance as a constituent of bronze has been considerably underrated and misunderstood. It has frequently been stated that the only use of phosphorus is as a deoxidiser, and that when the quantity present is in excess of that necessary to destroy the oxides in the alloy the bronze is inferior in quality. This statement requires considerable modification, as in many cases an excess of phosphorus is purposely added, and is found to confer valuable properties upon the alloy. The mistake, however, has probably arisen from the fact that the bronzes containing phosphorus have very different properties to those of ordinary bronze, and are very frequently not adapted to the same purposes.

The term phosphor-bronze is applied to many alloys, and to avoid confusion these may be grouped into three classes:—

1. Bronzes of ordinary composition, in which phosphorus has been employed solely as a deoxidiser, not more than a trace being present in the bronze.

2. Bronzes containing less than 9 per cent. of tin and only traces of phosphorus. These are frequently put on the market as "Rolled or Malleable Phosphor-Bronze."

3. Bronzes containing more than 9 per cent. of tin and an excess of phosphorus (usually from 0·2 to 2·0 per cent.), and sold as "Cast Phosphor-Bronze." Among this group may be placed the bronzes containing phosphorus and lead used as bearing metals.

The bronzes in Class 1 call for no special remark, as they are merely ordinary bronzes free from oxides. Those of Class 2 can be employed for all purposes for which copper and soft bronzes are used, such as boiler tubes, condenser tubes, pump rods, piston rods, boiler stays, firebox stays, bolts, nuts, etc. When cold rolled these bronzes show a breaking strain as high as 30 tons per sq. in. or even more, with an elastic limit of about 26 tons per sq. in.; while the same bronzes, after annealing, give a breaking strain of 20 tons per sq. in. and an elastic limit of about 7 tons per sq. in.

Rolled phosphor-bronze is also used for making boiling vats, tanks, stills, and parts of machinery working in liquids, on account of its superior resistance to corrosion.

At first sight it appears strange that these bronzes should resist corrosion better than ordinary bronzes, considering that they are of exactly the same composition; but the resistance to corrosion is due to the absence of oxide in the metal; for it must be remembered that such impurities have a very decided influence on the rate of corrosion. This subject will be considered at greater length in another chapter.

Rolled phosphor-bronze does not suffer any serious loss of strength at temperatures up to 300° C., and it is frequently recommended for firebox plates and stays.

The following tables give some results of tests made upon two well-known brands of rolled phosphor-bronze :—

Sample.	Condition.	Breaking Stress. Tons per sq. in.	Elastic Limit. Tons per sq. in.	Elongation per cent. on 2 ins.
1	Unannealed sheet	28·3	25·0	18·5
2	,, ,,	33·8	31·5	17·0
3	,, ,,	31·9	31·7	17·5
4	Annealed sheet	20·3	7·8	57·0
5	Sheathing plate	30·1	...	18·7
6	Bolt	28·8	27·5	26·6
7	Loco. firebox plate annealed	20·0	...	64·06

Samples 1 to 4 are by the Phosphor-Bronze Company, and samples 5 to 7 are "Melloid," by Bull's Metal and Melloid Company.

Much depends, of course, on the extent of the rolling; but by way of comparison it may be taken that the breaking stress of copper varies from 13 tons per sq. in. in the annealed condition to about 18 tons per sq. in. when rolled.

As regards the tensile strength of rolled phosphor-bronze at elevated temperatures, experiments carried out on a "Melloid" bolt showed that the breaking stress fell from 28·82 tons per sq. in. at the normal temperature to 25·51 tons per sq. in. at 315°. On an annealed bolt of the same material the breaking stress fell from 19·22 tons per sq. in. at the normal temperature to 18·80 tons per sq. in. at 214°; while a similar bar of copper, tested under the same conditions, fell from 13·84 to 10·25 tons per sq. in.

From what has been said of the constitution of the copper-tin alloys it will be seen that the rolled phosphor-bronzes which have been placed in Class 2 are solid solutions, and exhibit a simple crystalline structure under the microscope.

The phosphor-bronzes of Class 3 differ considerably from those of Class 2 and also from those of Class 1. Their constitution is somewhat complex, but of considerable interest. M. Guillemin pointed out in a communication to the Commission des Méthodes d'Essai in 1894 that under the microscope phosphor-bronzes exhibit a structure resembling a fern leaf or fir branch, and that this structure is not easily confounded with an ordinary bronze. It is doubtful, however, whether this can be regarded as the invariable structure of phosphor-bronzes, as sometimes the structure of ordinary bronze resembles it very closely. Guillet states that the phosphorus appears to enter into the α solution (*i.e.* the solution of tin in copper containing less than 9 per cent. of tin). If the alloys are examined under a high magnification it will be seen that this is not the case, but the reason of the mistake will also be apparent. It has already been shown that in bronzes containing more than 9 per cent. of tin a constituent δ ($SnCu_4$) separates out on cooling, and that this constituent is of a pale bluish-white colour. Now, if an excess of phosphorus is present in such an alloy it separates out on cooling in the form of phosphide of copper, which has very nearly the same colour as the $SnCu_4$ constituent, but slightly darker in shade. Moreover, these constituents, having melting-points lower than that of copper, occur side by side (in fact, they form a eutectic); and unless seen under a high magnification they appear as one constituent. On account of the similarity in colour it is extremely difficult to obtain a photograph, but by using a suitable screen it is possible. Photographs 14 and 15 show the fern-like structure referred to by Guillemin, and photograph 16 shows the combination of $SnCu_4$ and phosphide existing partly as eutectic. The eutectic of the two compounds is shown in photograph 18.

By means of heat-tinting, the different constituents can be readily distinguished; the phosphide colouring a beautiful blue, while the $SnCu_4$ is coloured yellow (photograph 17, and frontispiece).

The presence of free phosphide of copper in these bronzes accounts for their properties, differing as they do from ordinary bronze, and is sufficient to explain their great value for certain purposes. If, for example, a phosphor-bronze is subjected to friction, it is obvious that the softer part of the alloy will be worn down, leaving the hard phosphide in relief. The alloy thus consists of intensely hard particles imbedded in a softer matrix, so that not only is the wearing surface largely decreased and the friction consequently reduced, but the rate of wear is practically the rate of wear of the hard body, phosphide of copper. Phosphor-bronze is therefore peculiarly adapted for the manufacture of the wearing parts of machinery, such as bearings and bushes, worms and worm wheels, slide faces, piston rings, etc., and has a much longer life than ordinary bronze. Moreover, as the hard particles of phosphide are set in a matrix or cement of a comparatively plastic material, the alloys are not as brittle as might be expected, but are capable of withstanding considerable shocks, and will suffer distortion without breaking.

The main feature, then, of phosphor-bronze is its remarkable hardness and resistance to wear; and it would appear that for parts of machinery subject to wear there is no alloy to surpass it. The effect of the addition of phosphorus to the copper-tin alloys is worthy of a little attention. Guillet has made a number of tests on bronzes, the results of which are embodied in the following table:—

Composition.			Tensile Strength. Tons per sq. in.	Elastic Limit. Tons per sq. in.	Elongation per cent. on 4 ins.
Copper.	Tin.	Phosphorus.			
90·93	9·03	0	15·6	5·9	23
90·85	8·92	Trace	16·8	7·2	30
89·18	9·60	0·47	13·6	5·9	6
89·07	9·78	0·91	11·9	5·9	4
88·83	9·18	0·92	11·0	6·5	3·5
88·80	9·32	1·17	11·9	5·5	2·5

From these results it appears that the addition of phosphorus lowers the breaking stress (after a first increase due to the elimination of oxides) and also the elastic limit and the elongation. After an addition of 0·47 per cent., however, the decrease is more gradual. It must be noted that the alloys tested by Guillet contain very appreciable quantities of zinc, a metal which should not be present in the best phosphor-bronze.

Phosphor-bronzes containing lead are used for bearings. They will be considered in the chapter dealing with antifriction metals; and it is only necessary to say here that the lead does not alloy with the bronze, but separates in the form of minute globules throughout the metal; while the phosphide of copper separates exactly as in the other bronzes. Hence a surface of the alloy contains a number of hard particles (phosphide) and also a number of soft particles (lead), thus fulfilling, as will be seen later, the necessary conditions of a good bearing metal.

The phosphor-bronzes most commonly employed contain (1) 8 to 10 per cent. of tin and 0·5 to 0·7 per cent. of phosphorus; (2) 10 to 12 per cent. of tin and 0·7 to 1 per cent. of phosphorus; (3) 10 to 12 per cent. of tin and 1 to 1·5 per cent. of phosphorus.

The first of these is suitable for valves, pinions, pumps, propellers, steam and boiler fittings, etc. It is harder and wears better than gun-metal. The second alloy is considerably harder than the first, and is suitable for worms and worm-wheels, valves, pumps, cylinders, motor gearing, etc. The third is an exceptionally hard alloy without being brittle, and is capable of withstanding the hardest wear. It is suitable for worms and worm-gearing, slide valves, bearings, and all cases in which the wear is excessive.

Such alloys may be described as true phosphor-bronzes; but there are many others that contain, at the most, traces of phosphorus, and it is probable that at the present time very little bronze of any description is made without the addition of a small quantity of phosphorus as a deoxidiser.

Manganese-bronze.

As in the case of phosphor-bronze, the term "manganese-bronze" is applied to alloys of very variable composition. It may be stated at the outset, however, that in the great majority of cases the expression is somewhat misleading, as the alloys differ very slightly in composition from the ordinary brasses. It is only in rare cases that a copper-tin alloy containing manganese is met with. These usually contain from 1 to 3 per cent. of manganese, which is often accompanied by 4 or 5 per cent. of zinc and some lead. Guillet cites two cases of alloys employed for hydraulic machinery at high pressures having the following composition:—

	I.	II.
Copper	82·0	83·5
Tin	8·0	8·0
Zinc	5·0	5·0
Lead	3·0	3·0
Manganese	2·0	0·5

Although such alloys are seldom used they are not without interest, and a passing reference may be made to the influence of manganese on the copper-tin alloys. Guillet has submitted a series of alloys, containing manganese in varying amounts, to mechanical tests, with the results shown in the table :—

Composition.			Tensile Strength. Tons per sq. in.	Elastic Limit. Tons per sq. in.	Elongation per cent. on 4 ins.
Copper.	Tin.	Manganese.			
90·93	8·82	0	15·6	5·9	23
90·12	9·20	Traces	17·1	5·7	28
87·64	10·41	1·67	13·6	6·4	20
89·38	8·61	0·69	10·4	6·2	7·5
85·87	8·76	3·10	7·5	7·5	0

From these results it would appear that the first effect of manganese (probably due to its influence as a deoxidiser, much in the same way as phosphorus) is to give a higher breaking stress and elongation. When present to the extent of more than traces, however, the alloy rapidly becomes brittle, unless zinc is present at the same time.

The addition of manganese to copper alloys was attempted by Stirling, Parkes, and others; but their efforts met with little success until, in 1876, Parsons introduced his method of adding manganese in the form of ferromanganese. These alloys proved successful, and are now largely used.

Putting aside the copper-tin alloys containing manganese, the alloys sold commercially as manganese-bronzes may be divided into two classes :—

1. Alloys of copper and manganese containing about 4 to 6 per cent. of manganese.

2. Alloys of copper and zinc to which ferromanganese has been added. These alloys frequently contain aluminium and sometimes tin, but the principal constituents are copper and zinc.

The alloys belonging to the first class have a somewhat limited application, their principal feature being their strength at high temperatures. For this reason they have been very largely adopted in this country and on the Continent for firebox-stays.

The addition of manganese to copper does not materially harden the copper, but raises the tensile strength. The following figures are the results obtained by Guillet for small additions of manganese :—

Cu.	Mn.	Tensile Strength. Tons per sq. in.	Elastic Limit. Tons per sq. in.	Elongation per cent. on 4 ins.
96·95	2·94	14·0	6·3	45
95·40	4·40	15·2	7·3	42
93·38	6·56	17 4	8·4	33·5

The complete series of copper-manganese alloys have not received much attention, but the alloys used commercially are solid solutions of manganese in copper. Photograph 20 shows a section of a firebox stay containing 96 per cent. of copper and 4 per cent. of manganese. With less than 9 per cent. of manganese the alloys can be rolled or drawn.

The use of these alloys for firebox stays will be considered in the chapter dealing with the behaviour of alloys at high temperatures.

The alloys of the second class are those most commonly met with under the name of manganese-bronzes, although they would be more accurately described as manganese-brasses. From a theoretical point of view they have been little studied, but it is evident from the number of constituents present that their constitution must be of a complex character. Many manganese-bronzes contain only traces of manganese, and some fail to show even traces on analysis. In these the manganese has probably served its purpose purely as a deoxidiser, but it has left behind it the iron with which it was associated, and the influence of this metal must be considered, as it occurs in by no means inappreciable quantities in nearly all these alloys. The addition of manganese alone (that is to say, without the simultaneous addition of iron) to the copper-zinc alloys has the effect of increasing the tensile strength and the elastic limit with a decrease in the elongation. The alloys also become harder and more brittle. As regards their constitution the manganese enters into solution, with the result that the micro-structure is the same as that of the copper-zinc alloys. This probably accounts for the statement made by Guillet that the micro-structure of manganese-brasses is the same as that of copper-zinc alloys; but the commercial varieties of these alloys invariably contain iron, usually in very much larger quantities than the manganese, and their structure is very different to that of the ordinary brasses. Photographs 21 and 22 show the structure of a forged manganese-bronze containing 58·6 per cent. copper, 38·4 per cent. zinc, 1·6 per cent. iron, and 0·02 per cent. manganese. Manganese-bronzes containing upwards of 60 per cent. of copper are suitable for forging and rolling, while those containing less than 60 per cent. of copper are used for castings; and both of these varieties are made in various qualities according to the purposes for which they are required. Manganese-bronzes suitable for forging or rolling, such as those manufactured by the Manganese-Bronze and Brass Company, have an ultimate strength ranging from 27 tons in the mild quality to 38 tons in the high quality, the elastic limit ranging from 10 to 20 tons, and the elongation from 20 to 45 per cent. If the metal is cold-rolled the ultimate strength can be obtained as high as 40 to 50 tons per square inch.

Bronzes of this description are used for studs, bolts and nuts, pump-rods, pins, keys, etc., and, in fact, for practically all purposes for which yellow brass or Muntz metal are used. It can also be drawn into tubes which can be easily bent, either hot or cold, and are much stronger than brass or copper tubes. On this account, together with its freedom from corrosion, it is largely used for hydraulic tubes under heavy pressure.

In the form of plates and sheets it is of value in cases where a metal is required to withstand corrosion, such as strainer plates, sheathing for yachts, pump valves, etc.

Cast manganese-bronze, like the rolled variety, is made in different qualities according to requirements, and has an ultimate tensile strength of from 32 to 38 tons per sq. in., with an elastic limit varying from about 15 to 19 tons per sq. in., and an elongation of about 15 to 30 per cent. on two inches.

It is exceedingly tough, and is used for parts of marine engines, hydraulic rams, valves and cylinders, etc. Probably its most important application is in the manufacture of propellers and propeller blades. As compared with iron or steel propellers it has many advantages. It is lighter, and therefore the strains on the shafting, bearings, etc., are considerably reduced. Further, it is practically unaffected by sea water, so that the propeller blades retain their smooth surface. In the case of iron and steel the pitting due to the corrosion of the sea-water causes a falling-off in the speed, and in time necessitates the renewal of the propeller. It has been stated that the substitution of a manganese-bronze propeller in place of an iron one increases the speed of a vessel by about half a knot for the same coal consumption. Moreover, the alloy is capable of being worked cold, and in several cases where the propeller blades have been injured by accidents they have been hammered into shape without any sign of breaking.

A minor, but not altogether unimportant, consideration is the fact that a bronze propeller is always of value as a copper alloy. These advantages more than compensate for the extra initial cost of a manganese-bronze propeller.

The addition of aluminium to manganese-bronze gives rise to a series of alloys possessing very remarkable and useful properties. Bronzes of this description have recently been placed upon the market under the name of "Immadium" by the Manganese Bronze and Brass Company. They have an ultimate tensile strength of 38 tons per sq. in. in the case of forgings, and 42 tons per sq. in. in the case of rolled rods, with an elongation of from 20 to 25 per cent., and are made of different qualities to suit requirements. The structure of these alloys is very similar to that of ordinary manganese-bronze, but of somewhat finer and closer grain, the aluminium appearing to enter the alloy in the form of a solid solution. Photographs 23, 24, 25, and 26 show the structure of two samples of Immadium-bronze. The alloys work perfectly and take a very fine polish. They may be used for all purposes where strength and toughness are required, but their most valuable property is the remarkable resistance to the action of corrosive liquids which they possess. On this account they have been largely used in the manufacture of rods, valves, and other parts of pumps having to deal with acid water.

Aluminium-bronze.

The term "aluminium-bronze" is applied to alloys of copper and aluminium containing from 2 to 10 per cent. of aluminium. With more than 10 per cent. the alloys rapidly become brittle, and beyond 11 per cent. they are valueless from an industrial point of view.

The first aluminium-bronze was made by Dr Percy, and its properties studied by Debray; but at that time aluminium was a rare and expensive metal, so that for many years the alloy, which was known as "aluminium gold," was regarded rather as a curiosity than a commercially useful alloy. With the introduction of electrical methods of reducing aluminium, however, aluminium bronze became a practical alloy, and was placed on the market by the Cowles Smelting Company, who manufactured alloys containing from 1¼ to 11 per cent. of aluminium, for which they claimed an ultimate tensile strength ranging from 9 tons per sq. in. in the 1¼ per cent. alloy to 50 tons per square inch in the 11 per cent. alloy. Since then the manufacture of aluminium has been much improved and the price lowered; but it is still sufficiently high to prevent the alloys being more extensively used.

The properties of the copper-aluminium alloys have been studied by Gautier, Le Chatelier, and Guillet, and, more recently, by Carpenter and Edwards, who have confirmed and extended the work of Guillet. The freezing-point curve of the series is shown in fig. 32, but, as already mentioned, we are only concerned with a small portion of the curve, viz. that of the alloys containing less than 11 per cent. of aluminium, as the other alloys (with the exception of a few represented by a small part of the curve at the other end, which will be considered later) are of no industrial importance. As regards the alloys lying between these two portions of the curve there is a definite compound corresponding to the formula $CuAl_2$, which forms a simple series of alloys with aluminium, having a eutectic containing 67 per cent. of aluminium. There is little doubt that a compound corresponding to the formula Cu_3Al exists, and, possibly, one corresponding to Cu_4Al; but these compounds do not form simple alloys with copper. They give rise to a series of solid solutions of a complex and unstable character.

Aluminium-bronzes may be conveniently divided into two groups, viz.—(1) those containing from 0 to 7·35 per cent. of aluminium; and (2) those containing from 7·35 to 10 per cent. Up to 7·35 per cent. the alloys consist of a single homogeneous solid solution and are extremely ductile (photographs 28 to 31);

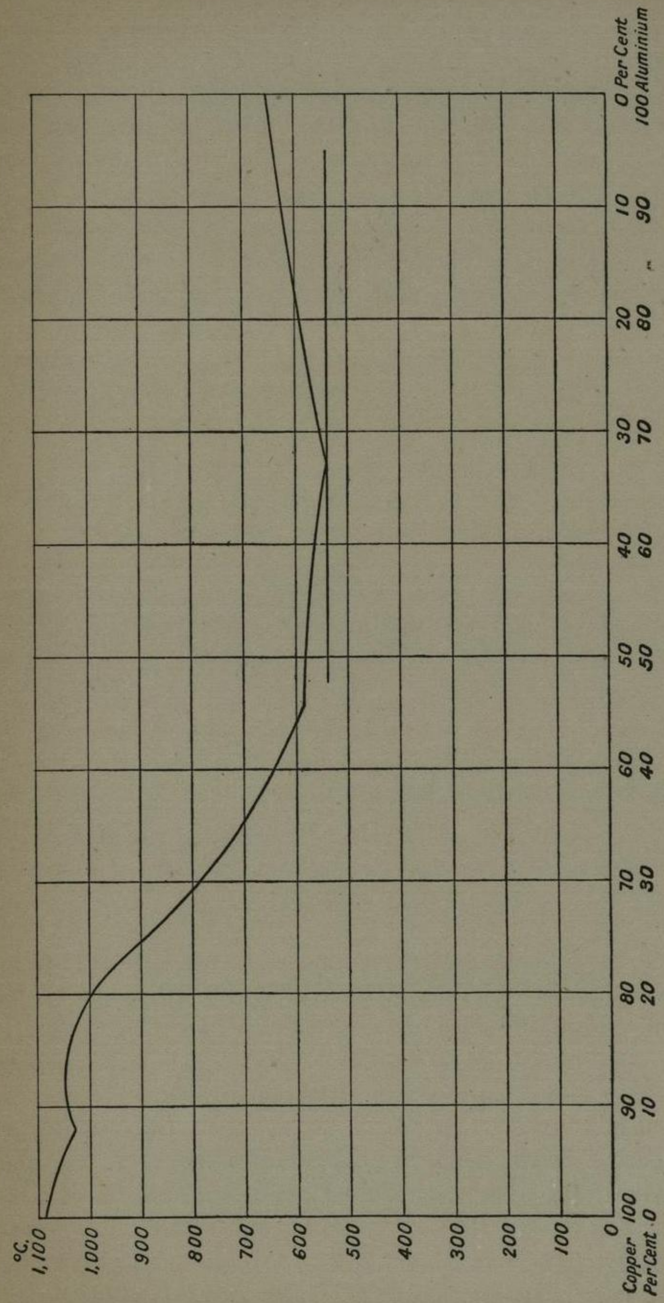

FIG. 32.—Freezing-point Curve of Copper-aluminium Alloys.

whereas the alloys containing more than 7·35 per cent. contain a hard, dark-coloured constituent which is accompanied by an increase in the tensile strength of the alloys and a decrease in ductility. The curves in figs. 33, 34 and 35 are plotted from the results obtained by Carpenter and Edwards on sand castings, rolled bars, and cold drawn bars respectively; and are quite in accordance with what would be expected from the microscopical appearance of the alloys.

The bronzes belonging to the first group (*i.e.* those containing less than 7·35 per cent. of aluminium) are very similar to high-grade brasses containing 70 per cent. of copper, and can be employed for many purposes in place of brass. The alloys can be readily forged and rolled, and can be drawn cold. Unfortunately, their high price is a serious drawback to their more extended use, except in special cases; but the alloys containing 2 per cent. of aluminium have been used in the manufacture of tubes and those containing 5 per cent. for rods, etc.; while, owing to their beautiful gold colour, they have been largely used for art castings and cheap jewellery.

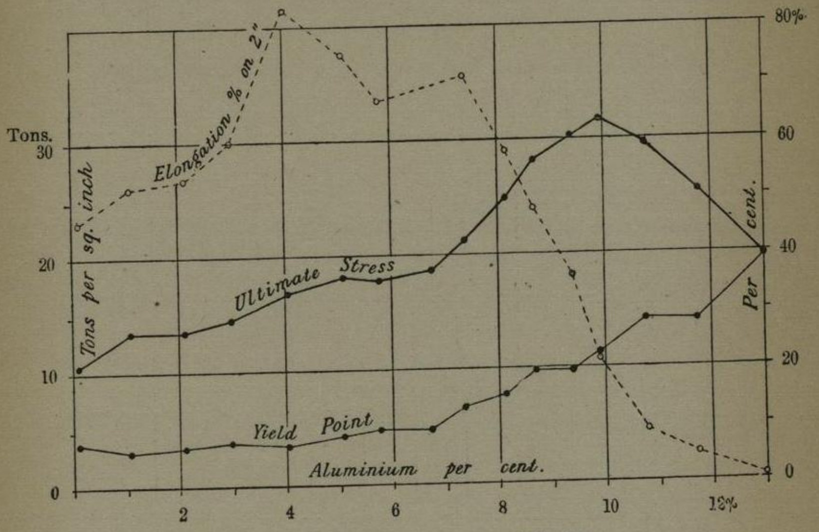

FIG. 33.—Tensile Tests on Sand Castings.

Many of the difficulties met with in brass, such as "season cracking," are also common to aluminium-bronze; and it has been

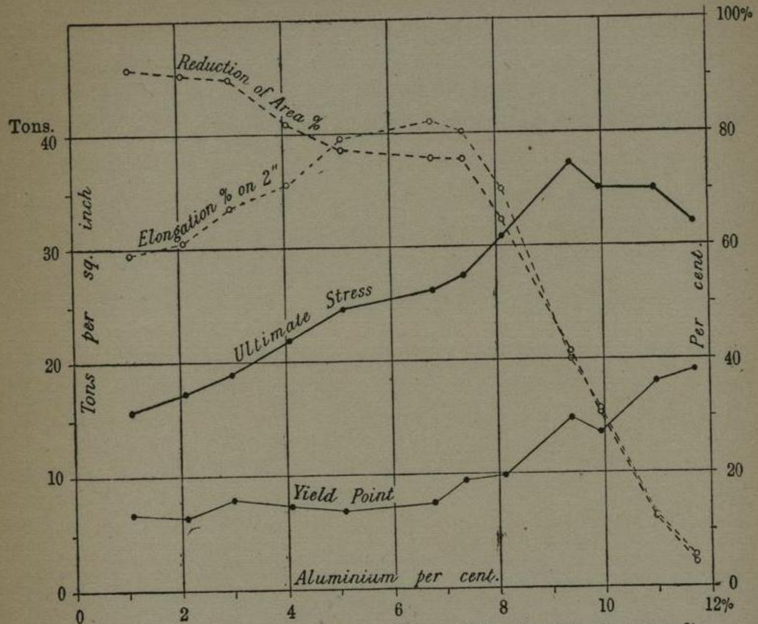

FIG. 34.—Tensile Tests on Bars rolled to 1¼ in. diameter (untreated).

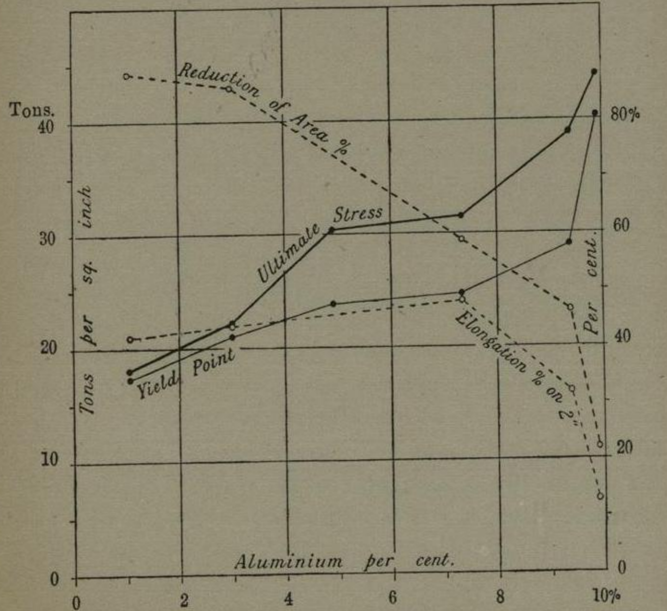

FIG. 35.—Tensile Tests on Rolled Bars Cold-drawn from ⅞ in. to $\frac{13}{16}$ in.

found that tubes which have received too great a pinch in the drawing will fracture in the course of a few months in exactly the same way as brass tubes. Moreover, on annealing aluminium-bronze the crystals increase in size, just as in the case of brass. This growth of crystal is accompanied by a decrease in the ultimate strength of the alloy and a very marked falling-off in the yield point. The accompanying table gives the results obtained by Carpenter and Edwards in the case of four alloys.

Aluminium.	Condition.	Yield-point.	Ultimate Stress.	Elastic Ratio.	Elongation on 2 in.	Reduction of Area.
Per cent.		Tons per sq. in.	Tons per sq. in.		Per cent.	Per cent.
	Rolled—					
0·10	Untreated	6·9	14·50	0·48	65·5	90·71
	One hour at 600° C.	5·0	14·11	0·35	65·0	91·60
	,, 900° C.	5·8	13·26	0·44	56·0	87·65
2·99	Untreated	11·6	19·79	0·59	57·25	86·11
	One hour at 600° C.	6·9	18·54	0·37	66·00	89·84
	,, 900° C.	5·8	19·76	0·30	82·5	83·60
5·76	Untreated	11·8	28·40	0·42	74·2	76·93
	One hour at 600° C.	9·4	27·20	0·33	77·0	75·00
	,, 900° C.	6·0	23·65	0·25	86·0	70·00
7·35	Untreated	10·6	29·68	0·36	72·5	74·34
	One hour at 900° C.	7·1	23·89	0·30	92·0	72·00

In these experiments the alloys were only heated for one hour; but a practical example of the effects of continued heating has been recorded in the case of a locomotive belonging to the London and North-Western Railway Company, which was fitted with aluminium-bronze firebox stays. After being in use for two months, during which time the locomotive had run only 2400 miles, it had to be taken off the road on account of the number of fractured stays. This question of the mechanical properties of alloys at temperatures above the normal is an exceedingly interesting one, and will be dealt with in more detail in another chapter.

As regards the general heat treatment of these alloys their properties appear to be little affected, whether slowly cooled or quenched. In this respect they differ from the alloys of the second group, containing more than 7·35 per cent. of aluminium. The curves in figs. 36, 37 and 38 show the results obtained by

Carpenter and Edwards on chill castings and on sand castings slowly cooled and quenched from 800° C.

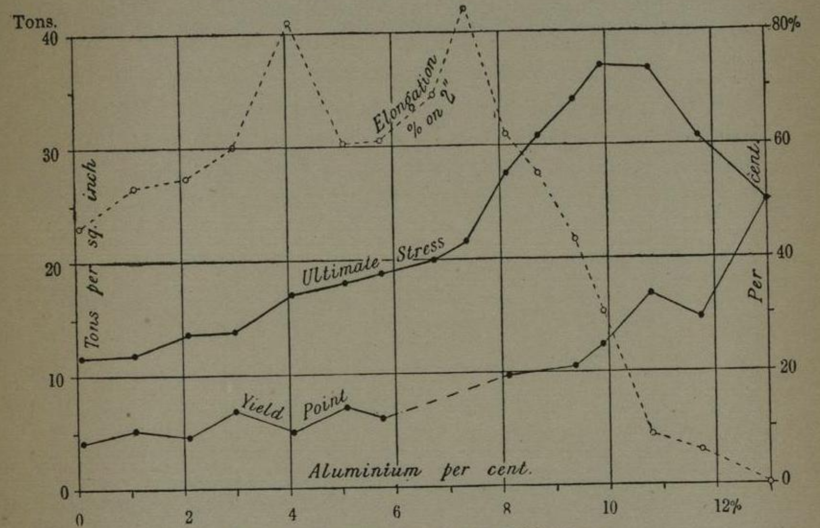

FIG. 36.—Tensile Tests on Chill Castings.

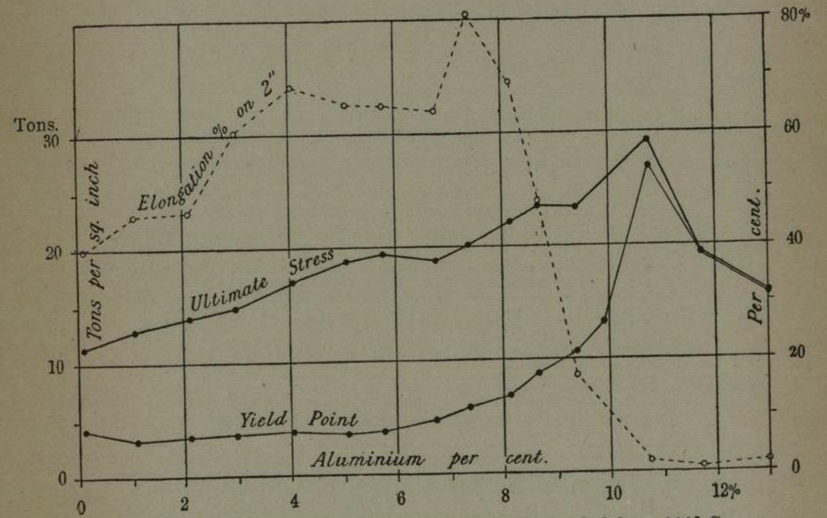

FIG. 37.—Tensile Tests on Sand Castings slowly cooled from 800° C.

The alloys belonging to the second group are composed of two constituents, the new component being a hard acicular mass, which was formerly supposed to be a eutectic (photograph 32); but when examined under high powers its structure can be easily distinguished from that of a eutectic. Photograph 33 shows the striated or acicular structure of this constituent. It appears to be a solution of an unstable character, as it is profoundly altered by heat treatment. Under prolonged annealing it gradually loses its structure and appears to reach a stable condition. Consequently, the alloys containing the constituent are considerably altered by thermal treatment, as shown in the curves. The bronzes of this class are still ductile, and have been used for propellers and propeller shafts.

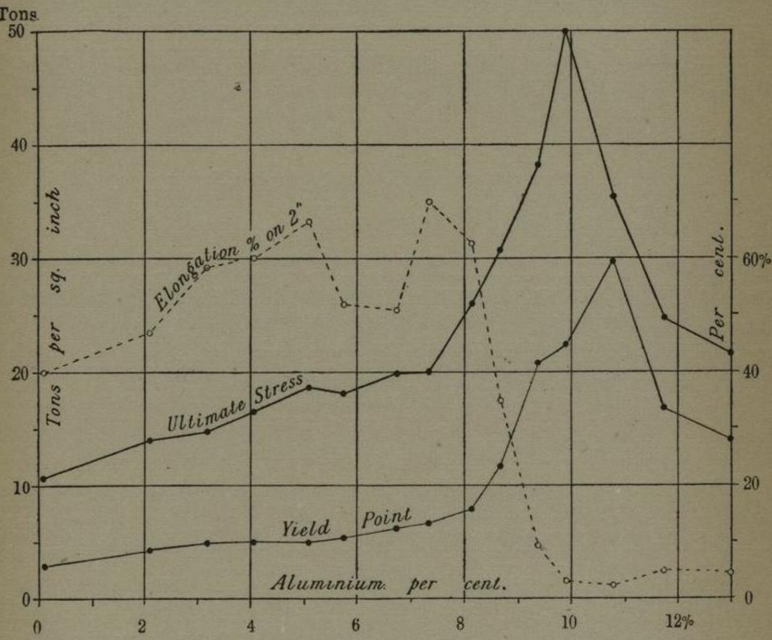

FIG. 38.—Tensile Tests on Sand Castings, quenched from 800° C. in Water.

Fig. 39 gives the curve representing the hardness of the series of alloys containing aluminium up to 15 per cent., as determined by the Brinell test, and illustrates very plainly the rapid increase in hardness caused by the appearance of the hard constituent.

The melting and casting of aluminium-bronze present no great difficulty. The alloys are melted in graphite crucibles under a layer of charcoal to prevent oxidation. Under these conditions very little alteration in composition is noticeable on remelting.

The fact recorded by several observers that copper and aluminium unite with the production of intense heat is due, not so much to the combination of copper and aluminium, as to the combination of the oxygen dissolved in the copper with the aluminium. The heat evolved on alloying deoxidised copper with aluminium is comparatively slight.

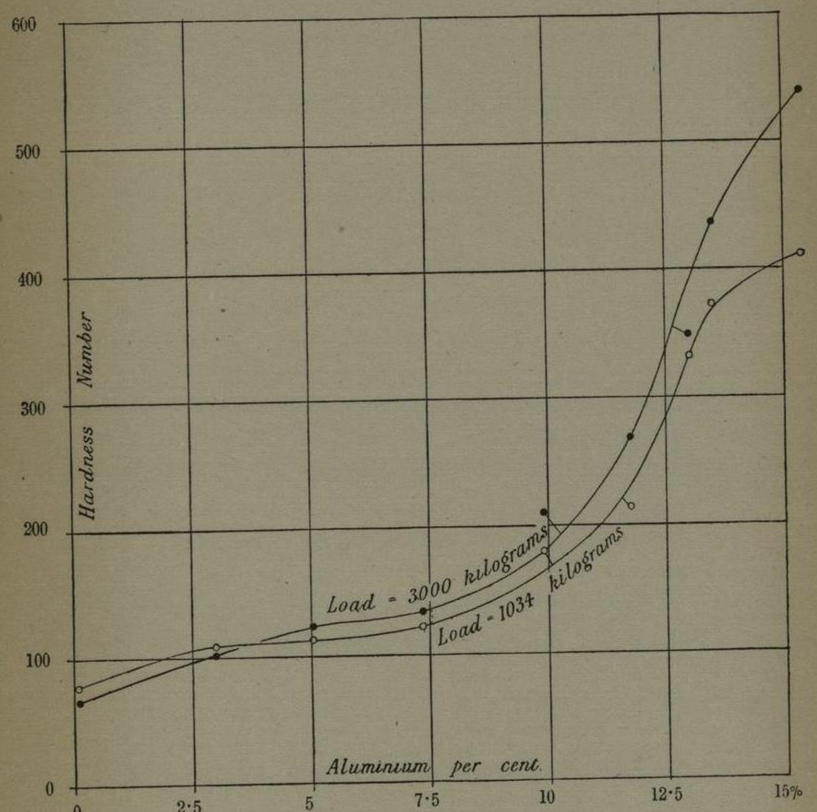

FIG. 39.—Hardness Number $\frac{\text{Load (kilograms)}}{\text{Superficies of Concavity } (mm^2)} \times \sqrt[5]{p}$

(where p = Radius of Hardened Ball).

Aluminium-bronze undergoes considerable contraction on cooling, and allowance must be made for this in casting the alloys, by providing large gates and a good head of the molten metal. The casting should also be carried out at as low a temperature as possible.

In addition to the binary alloys of copper and aluminium, alloys containing a small percentage of nickel have been placed on the market. The addition of nickel appears to give a harder and stronger alloy, but there is very little available information as to their practical uses.

Aluminium-bronzes containing 1 to 2 per cent. of silicon have also been placed on the market under various trade names. The addition of silicon has the effect of increasing the tensile strength of the alloy, while the falling-off in the elongation appears to be very considerable.

Aluminium-brass.

Aluminium-brass, as its name implies, is a brass containing a small quantity—not exceeding 4 per cent.—of aluminium. The alloys were placed on the market by the Cowles Electric Smelting Company, together with an alloy containing iron in addition to aluminium, which was known as **Hercules metal**. These alloys are still in use, and reference has already been made to manganese-brasses containing aluminium.

The constitution of aluminium-brasses has been studied by Guillet, and his results are of considerable interest. His experiments have been carried out on the two important types of brass containing respectively 30 and 40 per cent. of zinc by adding increasing quantities of aluminium. He finds that the structure of the alloys is the same as that of the common brasses, the aluminium appearing to have the same effect as zinc, but to a greater degree. Thus an alloy containing 38 per cent. of zinc and 2 per cent. of aluminium has the structure of a brass containing 45 per cent. of zinc; and this holds good with all the alloys, so that Guillet argues that in these alloys 1 per cent. of aluminium is equivalent to 3½ per cent. of zinc.

With more than 4 per cent. of aluminium the alloys are difficult to work.

Aluminium-brass gives excellent castings, and can be rolled and forged while hot. It is suitable for pumps, valves, pinions, etc., and also for propellers. Guillet states that the alloys have been used in France for the construction of submarines, but that they have not proved entirely satisfactory.

The mechanical properties of several of the alloys have

also been determined by Guillet, and his results are shown in the following table:—

MECHANICAL TESTS ON CAST ALLOYS.

Composition.			Tensile Strength in tons per sq. in.	Elastic Limit in tons per sq. in.	Elongation per cent.
Copper.	Zinc.	Aluminium.			
70·0	29·6	0 0	8·7	3·6	50
69·0	29·9	0·4	12·6	2·9	59
70·0	28·8	0·9	14·4	4·2	67
70·5	26·4	3·1	21·5	8·5	50
70·1	24·7	5·2	32·2	4·7	11
60·0	40·0	0·0	20·2	5·1	47
59·6	40·1	0·3	20·5	6·2	51
59·9	40·3	0·8	19·6	6·0	45
59·6	38·5	2·9	29·2	7·5	14
60·4	35·9	4·7	28·0	11·3	2

MECHANICAL TESTS ON ALLOYS, ROLLED, DRAWN AND ANNEALED.

Composition.			Tensile Strength in tons per sq. in.	Elastic Limit in tons per sq. in.	Elongation per cent.
Copper.	Zinc.	Aluminium.			
61·4	38·4	0·7	22·3	6·4	45
60·3	38·2	1·1	24·2	7·1	36
61·0	37·7	1·4	23·3	7·8	43
59·9	37·9	2·0	24·8	11·5	17
59·8	37·2	2·7	28·2	11·2	16
60 0	36·4	3·9	30·5	11·6	13

BIBLIOGRAPHY.

Carpenter and **Edwards**, "Eighth Report, Alloys Research Committee," *Inst. Mech. Engineers.*
Charpy, *Contribution à l'étude des Alliages.*
Guillet, *Les Alliages Métalliques.*
Le Chatelier, *Contribution à l'étude des Alliages.*
Lewis, *Jour. Soc. Chem. Ind.*, 28th May 1902.