CHAPTER XII.

ANTIFRICTION ALLOYS.

In a perfectly adjusted and lubricated bearing there is a thin layer of oil between the journal and the bearing, so that the metals never come in contact, and the friction, as has been shown by Osborne Reynolds, and others, is merely that between a solid and a liquid, and depends solely upon the nature of the lubricant. It follows that the nature of the metal of which the bearing is composed is immaterial; but such perfect adjustment is not attained in actual practice, and the problem presents itself of finding a metal or alloy sufficiently plastic to mould itself to the shape of the shaft, thus automatically rectifying imperfections of adjustment, and at the same time offering a minimum of friction. The use of lead was first suggested, according to Thurston, by Hopkins; but this metal is too soft and easily deformed, and soon gave place to white-metal alloys. Apparently the manufacture of these alloys was not entirely satisfactory, for in 1852 Mr Nozo of the Compagnie des Chemins de fer du Nord stated that they could be used advantageously with small load and medium speed but that for railroad vehicles they were not satisfactory. Since the publication of this statement antifriction metals have been greatly improved, and they are now very largely used. Mr Salomon, the chief engineer of the Chemins de fer de l'Est, has stated that the statistics on that railway have shown a decided advantage in favour of white metal over bronze; and Mr Chabal, the assistant engineer of the Paris, Lyon, Méditerranée Railway records that white-metal bearings become heated much less often than bronze, the wear also being less.

Since the introduction of white-metal bearings an immense number of so-called antifriction metals have been placed upon the market (some of which are given in the tables on pp. 200–202), and it becomes a matter of importance to determine what are the essential characteristics of a good bearing metal and to what extent these antifriction metals possess those characteristics.

In 1820 Rennie showed that the friction between two bodies under pressure increases proportionately to the pressure until a certain point is reached, when the two surfaces begin to rub against one another, causing a sudden increase in the coefficient of friction and consequent heating of the bodies. The pressure required to produce this sudden increase in the friction is greater with hard metals than with soft, and, at the same time, the coefficient of friction is smaller with hard metals than with soft ones.

The first conclusion we arrive at, then, is that a bearing metal should be as hard as possible. But this conclusion assumes a perfectly adjusted bearing in which contact between the shaft and the bearing is perfectly uniform—a condition which is rarely met with, especially in the case of a shaft supported by a number of bearings. If contact only takes place at a few points, the result will be heating and cutting. The second requirement of a good bearing metal, therefore, is that it must be sufficiently plastic to adapt itself to any imperfections of adjustment. A combination of these two requirements, hardness and plasticity, can only be obtained by having a body consisting of small, hard particles embedded in a plastic matrix; and this result is most easily produced by alloying a soft metal, such as lead or tin, with one or more metals which form definite compounds capable of crystallising out in the cooling mass. This, in fact, is the structure of antifriction alloys; but much depends, as will be seen presently, on the size and number of the hard crystals.

For the sake of convenience, the bearing metals may be divided into five groups :—

I. Alloys consisting essentially of tin, containing compounds of tin and antimony, and tin and copper. These form a very large class.

II. Alloys consisting essentially of lead, or lead and tin, containing a compound of tin and antimony. These alloys are largely used on account of their low price.

III. Alloys consisting essentially of a solid solution of copper and tin (or copper and zinc), and containing compounds of copper and tin, copper and phosphorus, etc.

IV. Alloys consisting essentially of a solid solution of copper and tin (sometimes containing zinc, nickel, etc.), and containing free lead. These constitute an important class of bearing metals.

V. Alloys other than those described above.

Alloys of Group I.—In all the alloys of tin, copper, and antimony in which the percentage of tin preponderates, only two definite compounds are formed, viz. a compound of tin and antimony, which crystallises in well-defined cubes and which is the same compound as that found in the binary alloys of tin and antimony. Its composition corresponds to the formula SnSb, and, according to Charpy, it is less hard and less brittle than pure antimony. The other compound is that found in the binary alloys of copper and tin, crystallising in hard needles, often forming stars, and having a composition corresponding to the formula $SnCu_3$. Both these compounds can be seen on a polished surface of the alloy, but etching with hydrochloric acid renders them more apparent. Photograph 35 illustrates the structure of a typical bearing metal of this type.

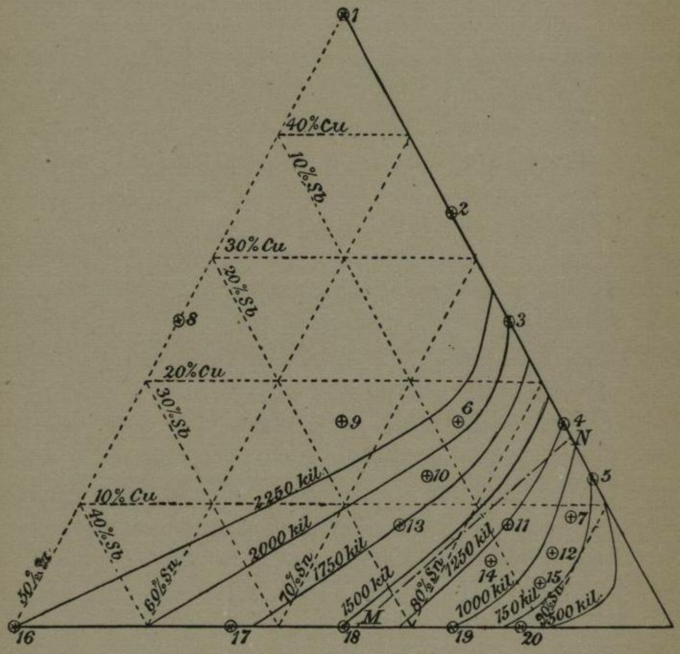

FIG. 41.—Compressive Strength of the Alloys of Tin, Copper, and Antimony.

Charpy has examined twenty alloys of copper, tin, and antimony, and his results on the compressive strength of these alloys, which were carried out on test pieces 15 mm. in height and 10 sq. mm. sectional area, are given in the following table, and are also plotted in the form of a triangular diagram (fig. 41). The curved lines represent the loads producing a compression of 0·2 millimetre.

Number of Alloy.	Composition.			Load corresponding to a Compression of 0·2 mm.	Load corresponding to a Compression of 7·5 mm.
	Tin.	Copper.	Antimony.		
1	50	50	...	Broke without deformation.	
2	66	34	...	2810 kgs.	Broke.
3	75	25	...	2000 ,,	,,
4	83	17	...	1325 ,,	2000
5	88	12	...	550 ,,	1550
6	75	8	17	2075 ,,	Broke.
7	88	4	8	875 ,,	2258
8	50	25	25	3760 ,,	Broke.
9	66	17	17	2780 ,,	,,
10	75	12·5	12·5	1730 ,,	,,
11	83	8·5	8·5	1200 ,,	2550
12	88	6	6	980 ,,	2550
13	75	17	8	1780 ,,	2550
14	83	11·5	5·5	1330 ,,	2750
15	88	8	4	1000 ,,	2475
16	50	...	50	2220 ,,	Broke.
17	66	...	34	1790 ,,	,,
18	75	...	25	1500 ,,	2600
19	83	...	17	1000 ,,	2650
20	88	...	12	600 ,,	2150

Alloys 1, 2, 3, 6, 8, 9, and 16 broke at the beginning of the compression, and Nos. 4, 10, 13, and 18 developed internal cracks before a compression of 7·5 mm. was reached. It follows that all these alloys are too hard, so that the line MN may be regarded as the limit of the useful alloys, and within this limit the alloy represented by No. 14 of the series has the greatest compressive strength. Alloys of approximately this composition are used by several railway companies for car bearings. Charpy states that the best alloys of this group should probably not differ from this composition by more than 3 or 4 per cent.

The method of casting and the rate of cooling of these alloys are of the utmost importance, and this subject has been carefully studied by Behrens and Baucke. They have shown that the hardness of the matrix of the alloy varies with the rate of cooling. In a rapidly cooled bearing this portion of the alloy solidifies with a greater percentage of copper and antimony, and its hardness may reach 2, tin being 1·7; while in a slowly cooled sample it may be as low as 1·6.

The size and number of the tin-antimony crystals also depends on the rate of cooling of the mass. In slowly cooled samples the crystals measure as much as 0·5 mm., while in chilled samples the crystals are small and imperfectly formed and can hardly be detected. Both these structures are met with in bearings which have become heated in service, whereas the structure of bearings which have proved satisfactory in service is intermediate between these two, the crystals being well formed and numerous, but not exceeding 0·25 mm.

As regards the proper temperature for casting, Behrens and Baucke cast three experimental bearings—one with a red-hot core, one with a core cooled by running water, and one with a core at 100° C. The first of these showed large tin-antimony crystals measuring 0·5 mm., and tin-copper crystals measuring 0·2 mm.; the second showed the confused structure of a chilled casting; and the third showed small tin-antimony crystals measuring 0·25 mm. The three bearings were then submitted to a practical test in the following manner. They were turned so as to fit a polished steel mandrel 15 mm. in diameter, which was capable of being rotated at a speed of 1600 revolutions per minute. The bearings were arranged so that the pressure on the blocks could be varied, and the rise in temperature was determined by means of thermometers fitted into holes in the blocks by soft amalgam. The increase in temperature, after running for one minute with pressures up to 3 kilograms per sq. cm., was as follows:—

	0·3 kg.	0·4 kg.	0·6 kg.	1·2 kg.	3 kg.
Red-hot core . .	0·65	1·60	1·72	2·62	4·64
Cold core . .	0·50	0·82	1·12	1·50	3·80
Core at 100° C. .	0·64	0·64	0·74	0·75	1·64

At the end of the experiment the chilled bearing showed irregular grooves and scratches, and the slowly cooled bearing was also badly scratched and grooved. The bearing cast at 100° C. showed the tin-antimony cubes partly rounded and the matrix surrounding them worn away, giving the impression that they might eventually be loosened and removed from their places. Evidently this actually occurs, for Behrens and Baucke submitted the oil from the bearings to a microscopical examination and found that it contained small spherical bodies like small drops of mercury, whereas the oil from bearings cooled too slowly or too quickly contained angular fragments. As the result of these observations Behrens and Baucke conclude that in a properly cast bearing the brittle rods of the tin-copper compound are crushed, and, acting as an abrasive, loosen and round the rectangular tin-antimony crystals, the result being that the bearing becomes practically a ball-bearing, with a rolling friction taking the place of a sliding friction. In a bearing which has been cooled too quickly the absence of the rectangular tin-antimony crystals prevents the formation of these spherical particles, and in a slowly cooled bearing the large crystals are broken instead of being rounded.

A study of the causes giving rise to heated bearings has shown that, in addition to the obvious cause of lack of proper lubrication, excessive heating is usually caused by: (1) defective crystallisation, due to the cooling taking place either too quickly or too slowly, usually the latter; (2) the presence of dross or scum in the metal; and (3) segregation of the metals, due to improper mixing or an attempt to alloy the metals in wrong proportions.

Alloys of Group II.—Before dealing with the triple alloys of this group it may be well to consider the simple alloys of lead and antimony, as they were formerly extensively used as antifriction alloys and their properties have been carefully studied by Charpy.

It will be remembered that lead and antimony give rise to simple alloys without the formation of any chemical compound. The eutectic contains 87 per cent. of lead and 13 per cent. of antimony, and on either side of the eutectic point the alloys consist of a single metal, lead in the one case and antimony in the other, surrounded by the eutectic.

Charpy has determined the compressive strength of these alloys, and his determinations of the loads corresponding to a permanent set of 0·2 mm. and 7·5 mm. in the case of pure lead, pure antimony, and seven alloys containing from 10 to 60 per cent. of antimony, are given in the following table :—

Composition of Alloy.	Load corresponding to a Permanent Set of 0·2 mm.	Load corresponding to a Permanent Set of 7·5 mm.	Remarks.
	Kilograms.	Kilograms.	
Pure lead . .	100	500	
10% antimony .	650	1300	
17·5% ,, .	650	1450	
20 ,, .	760	...	Broke at 1250 kgs.
30 ,, .	770	...	,, 1400 ,,
33 ,, .	800	...	,, 1400 ,,
50 ,, .	950	...	,, 1475 ,,
60 ,, .	1060	...	,, 1700 ,,
Pure antimony .	...	...	Broke at 1450 kgs. without any appreciable compression.

It will be noticed that the compressive strength increases with the increase of antimony until the eutectic is reached. On passing this point, however, there is only a slight increase in the compressive strength, due, as Charpy points out, to the fact that the antimony grains are isolated and merely transmit the load to the eutectic in which they are embedded. But when the antimony grains become sufficiently numerous to come in contact with one another they bear a portion of the load and the alloy becomes brittle, the brittleness increasing as the proportion of the plastic eutectic decreases.

In the alloys composed of lead, tin, and antimony the only compound formed is that of tin and antimony. This compound is the same as that which occurs in the tin-copper-antimony alloys, and it forms solid solutions with antimony.

The results of compressive tests on ten of these alloys are shown in the following table, and the curves corresponding to loads of 500, 750, 1000, and 1250 kilograms are plotted in the triangular diagram (fig. 42). Alloys possessing a greater compressive strength than 1250 kilograms were brittle, and Nos. 7, 8, and 9 of the series tested were badly cracked.

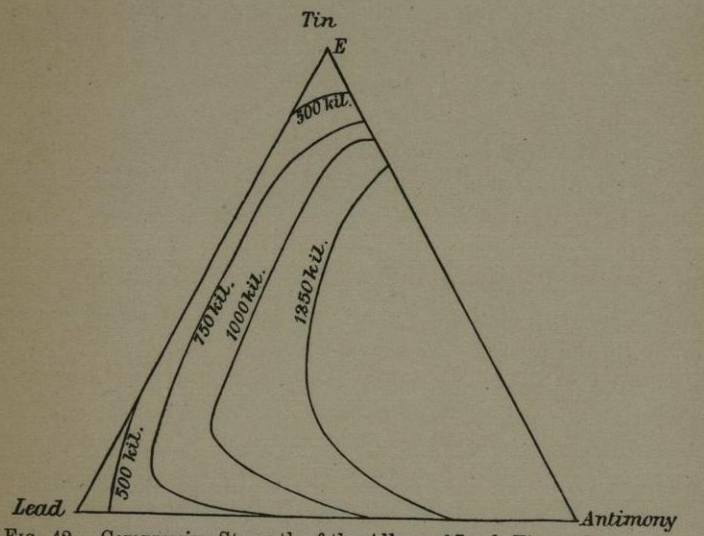

FIG. 42.—Compressive Strength of the Alloys of Lead, Tin, and Antimony.

Antimony increases the hardness of the alloys, and should not exceed 18 per cent. if the alloys are not to be brittle.

No. of Alloy.	Composition.			Load corresponding to a Compression of 0·2 mm.	Load corresponding to a Compression of 7·5 mm.
	Lead.	Tin.	Antimony.		
				Kilograms.	Kilograms.
1	...	100	...	300	1060
2	20	80	...	600	1750
3	40	60	...	650	1475
4	60	40	...	600	1400
5	80	20	...	475	1150
6	10	80	10	1100	2700
7	20	60	20	1350	2200
8	40	40	20	1150	1825
9	60	20	20	1050	1700
10	80	10	10	800	1775

Charpy states that the alloys of lead, tin, and antimony are similar to those of lead and antimony ; but, owing to the solubility of the compound SnSb in the antimony, the addition of tin diminishes the hardness and brittleness of the hard grains and also increases the compressive strength of the eutectic alloy. For these reasons the alloys of lead, tin, and antimony are superior to those of lead and antimony alone. The tin must be present to the extent of more than 10 per cent., but not necessarily more than 20 per cent., and the antimony may vary between 10 and 18 per cent.

Alloys of Group III.—Although these alloys are, strictly speaking, not antifriction alloys, they are largely used for bearings and other parts of machinery subject to frictional wear. Their constitution has already been considered, and it is only necessary to repeat that in the case of the copper-tin alloys containing more than 9 per cent. of tin the hard compound $SnCu_3$ separates out; while in the case of the alloys containing phosphorus, a hard compound PCu_3 separates out and forms a eutectic with the $SnCu_3$. It is evident that these alloys possess much the same features as the other antifriction alloys, viz. particles of a hard compound embedded in a softer matrix. In the copper-tin alloys, however, the matrix is a solid solution of tin in copper and is very much harder than the tin and lead alloys, and it follows that the plasticity of the copper alloys is very inferior to that of the true antifriction alloys.

Charpy gives the following results of compression tests on some of the copper-tin alloys, together with their analyses. A compression of 7·5 mm., as in the tests on the other alloys already quoted, was not practicable on account of the greater hardness of the alloys; but comparative results were obtained by measuring the compression produced by a load of 5000 kilograms.

No. of Alloy.	Composition.						Load corresponding to a Compression of 0·2 mm.	Compression produced by a Load of 5000 kgs.
	Cu.	Sn.	Pb.	Sb.	P.	Zn.	Kilograms.	Millimetres.
1	89·45	9·05	0·68	0·25	0·107	0·44	1925	3·7
2	88·55	10·32	0·25	0·13	0·223	0·40	2100	3·1
3	86·79	11·20	0·44	0·31	0·11	1·17	2350	3·2
4	85·70	12·15	0·51	0·12	0·385	0·84	3000	2·5
5	84·83	13·41	0·38	0·13	0·46	0·59	3100	2·1
6	84·30	14·60	0·40	0·10	0·215	0·56	3600	1·9
7	80·65	19·18	0·04	0·21	0·03	...	5000	1·4

Alloys of Group IV.—Alloys of copper and tin containing relatively large quantities of lead have recently been largely used as antifriction metals, and are frequently known as *plastic bronzes.* The lead, which may reach as much as 30 per cent., does not alloy with the copper, but separates out in the form of globules, which ought, if the alloy is properly mixed and cast, to be uniformly distributed throughout the mass of the alloy. The constitution of these alloys differs somewhat from other antifriction alloys, for, instead of hard particles embedded in a soft matrix, we have soft particles embedded in a comparatively hard matrix. The addition of lead increases the plasticity of the bronze, as is shown by Charpy's compression tests given below:—

No. of Alloy.	Composition.						Load corresponding to a Compression of 0·2 mm.	Compression produced by a Load of 5000 kgs.
	Cu.	Sn.	Pb.	Sb.	P.	Zn.	Kilograms.	Millimetres.
1	83·35	6·60	8·44	0·16	...	0·10	1500	4·8
2	80·55	2·25	10·86	2·67	0·21	0·60	1500	4·8
3	84·70	10·05	4·00	0·14	0·11	0·46	2000	3·2
4	82·30	8·98	7·27	0·14	0·39	0·10	2700	2·4

In addition to the ordinary lead-bronzes there are the bronzes containing phosphorus and those containing nickel. The addition of phosphorus introduces the hard compound Cu_3P, and, although comparative data are lacking, it seems probable that the presence of this constituent has an important influence on the properties of the bronze.

Photograph 19 shows a phosphor-bronze containing lead, unetched. The hard compounds $SnCu_3$ and PCu_3 can be distinctly seen standing in relief, but most of the lead has been torn out in the process of polishing, leaving pits which appear as black dots in the photograph.

The addition of a small quantity of nickel is said to enable a larger amount of lead to be added to the bronze without causing segregation. These bronzes are now largely used in America, and contain as much as 30 per cent. of lead and 1 per cent. of nickel. The part played by the nickel has not been fully explained.

In addition to the alloys already dealt with, there are certain alloys of zinc, tin, and antimony, which are used for special purposes, and also alloys of lead, copper, and antimony, which are occasionally employed as antifriction metals. The alloys of zinc, tin, and antimony possess a high compressive strength, as shown by Charpy's figures given in the table, and they are employed for bearings of machinery, such as rock-breakers, where strength is of more importance than perfect antifrictional qualities.

No. of Alloy.	Composition.			Load corresponding to a Compression of 0·2 mm.	Load corresponding to a Compression of 7·5 mm.
	Zinc.	Antimony.	Tin.		
				Kilograms.	Kilograms.
1	100	...	...	500	4200
2	90	10	...	2450	Broke at 5000
3	80	20	...	3000	,, 4000
4	70	30	...	4100	,, 4700
5	90	5	5	1100	3950
6	80	10	10	1350	4150
7	70	15	15	1800	5200
8	80	5	15	1120	3550
9	70	7·5	22·5	1225	3500
10	60	10	30	1240	3350
11	90	...	10	750	3050
12	80	...	20	850	2725
13	70	...	30	850	2500
14	60	...	40	575	2175

Zinc and tin do not unite to form definite compounds, but zinc and antimony combine to form a hard compound, which Charpy describes as an antimonide of zinc.

The useful alloys are those rich in zinc, in which the hard compound is the first to solidify.

The alloys of lead, copper, and antimony have similar characteristics to the other antifriction alloys. The copper unites with the antimony to form the hard violet-coloured compound $SbCu_2$, part of which crystallises in needles and the remainder enters into the composition of the eutectic. The alloys should contain from 15 to 25 per cent. of antimony and not more than 10 per cent. of copper. The results of some compressive tests on these alloys are given by way of comparison.

No. of Alloy.	Composition.			Load corresponding to a Compression of 0·2 mm.	Load corresponding to a Compression of 7·5 mm.
	Lead.	Copper.	Antimony.		
				Kilograms.	Kilograms.
1	66·6	...	33·4	750	1250
2	66·6	12·9	20·5	1120	1325
3	66·6	23·2	10·2	350	850
4	80	7·75	12·25	730	1525
5	80	13·9	6·1	200	800
6	80	...	20	640	1400
7	90	3·8	6·2	440	1325
8	90	6·9	3·1	190	800
9	90	...	10	640	1400
10	100	...	...	80	550

As regards the relative merits of white-metal and bronze bearings it is frequently stated that white metal is superior, and some writers have brought forward experimental evidence to prove their statements.

Charpy says that bronzes appear to be inferior to white metals on account of their lack of plasticity and their tendency to cutting; and in connection with railway axle bearings the same opinion has been expressed, as already mentioned, by Mr Salomon and Mr Chabal. On the other hand, Mr Clamer states that railway engineers only recognise two alloys as standrard, viz. phosphor-bronze containing lead, and ordinary bronze containing lead. General comparisons are always dangerous and frequently misleading and the truth of the matter would seem to be that white metals and bronzes each have their particular uses for which they are best adapted. In cases where accuracy of adjustment is impossible, as in the case of a long shaft requiring several bearings, or where variable forces come into play with a tendency to irregular wear, as in the case of railway bearings, the plasticity of white metal is an invaluable property. On the other hand, where accuracy of adjustment is possible and the rotary motion regular, plasticity is of secondary importance, and bronzes give results in practice which leave nothing to be desired.

Alloys of Tin, Copper, and Antimony.

Composition.			References and Remarks.
Tin.	Copper.	Antimony.	
96	4	8	Thurston. Ordinary bearings.
90	2	8	Thurston. Russian railroads for car bearings.
88·8	3·7	7·4	Thurston. Karmarsch metal.
87	6	7	Hiorns. For heavily loaded bearings.
85	5	10	Ledebur. Jacoby metal.
83·33	5·55	11·11	Used for car bearings on French railroads.
83	6	11	Ledebur. Used by Berlin railroads.
82	6	12	Ledebur. Used by Orleans and the Western Austrian railroads.
82	8	10	Bearings for valve rods and eccentric collars.
80	10	10	Thurston. Used by Swiss railroads.
78·5	10	11·5	Thurston. Used by Russian railroads.
71	5	24	Thurston standard white metal. Used for packing of valves and eccentric collars.
67	22	11	Thurston. Used by Great Western Railway.
67	11	22	Used by French state railroads.

Alloys of Lead, Tin, and Antimony.

Composition.			References and Remarks.
Lead.	Tin.	Antimony.	
80	12	8	Used by Eastern railroad (France) for metallic packings.
77·7	5·9	16·8	Quoted by Thurston as being the composition of Magnolia and Tandem metals.
76	14	10	Used for metallic packings by the Orleans and Paris L. M. railroads.
73	12	15	Used by Northern Co. (France) for metallic packing of piston-rods.
70	20	10	Metallic packings of eccentric collars. French state railroads.
68	15	17	"Graphite" metal analysed by Dudley.
60	20	20	Ledebur. Railroad bearings.
42	46	12	Hiorns. Hoyles metal.
42	42	16	Ledebur. Journal boxes. French state railroads.
37	38	25	Thurston. Italian railroad companies.

Alloys of Copper and Tin containing Zinc, Phosphorus, etc.

Composition.					References and Remarks.
Copper.	Tin.	Zinc.	P.	As.	
86	14	...	...	...	Thurston. Locomotive bearings.
82	18	...	...	...	Ledebur. Car bearings of "Compagnie du Nord."
84	14	2	...	...	Used by French state railroads for pieces subjected to alternating friction.
82	16	2	...	...	Used by French state railroads for pieces subjected to circular friction.
80	18	2	...	...	Thurston Lafond alloy.
58	28	14	...	...	Thurston. Margraff alloy.
56	28	16	...	...	Thurston. Fenton alloy.
89	10	...	...	0·8	Dudley. Arsenic-bronze.
85·7	12·2	...	0·4	...	Charpy. Phosphor-bronze.
84·8	13·4	...	0·46	...	Charpy. Phosphor-bronze.
88·7	9·5	...	0·7	...	Law. Phosphor-bronze.
87·6	10·8	...	1·0	...	Law. Phosphor-bronze.

Bronzes containing Lead.

Composition.						References and Remarks.
Copper.	Tin.	Lead.	P.	As.	Ni.	
79·7	10	9·6	0·8	...	...	Dudley's "standard" phosphor-bronze.
77	8	15	...	...	...	Dudley's "alloy B."
83·3	6·6	8·4	...	...	...	Charpy.
80·5	2·2	10·8	0·2	...	...	Charpy.
82·3	8·9	7·2	0·4	...	...	Charpy.
75·4	9·7	14·5	...	...	...	Carbon-bronze analysed by Dudley.
78·5	9·2	15·0	...	...	...	Graney bronze ,, ,,
76·4	10·6	12·5	...	...	...	Damar bronze ,, ,,
81·2	10·9	7·2	0·4	...	...	Ajax bronze ,, ,,
79·2	10·2	9·6	0·9	...	...	Phosphor-bronze ,, ,,
76·8	8	15	0·2	...	...	B. metal. Car bearings of the Pennsylvania railroad.
82·2	10·0	7·0	...	0·8	...	Dudley. Arsenic-bronze B.
79·7	10·0	9·5	...	0·8	...	,, ,, C.

MISCELLANEOUS ALLOYS.

Composition.						References and Remarks.
Cu.	Sn.	Pb.	Zn.	Sb.	Fe.	
5	...	...	85	10	...	Ledebur.
70·2	4·2	14·7	10·2	...	0·5	Camelia metal analysed by Dudley.
4·0	9·9	1·1	85·5	...	...	Salge ,, ,, ,,
92·4	2·4	5·1	...	...	0·1	Delta ,, ,, ,,
59·0	2·1	0·3	38·4	...	0·1	Tobin bronze ,, ,,
55·7	0·9	...	42·6	...	0·7	Harrington bronze ,, ,,
6	14	...	80	...	...	Thurston. Fenton alloy.
5·5	17·5	...	77	...	...	Ledebur.

BIBLIOGRAPHY.

Behrens and **Baucke**, *The Metallographist*, 1900, vol. iii.

Charpy, "Contribution à l'étude des alliages métalliques," *The Metallographist*, 1899, vol. ii.

Chabal, *Revue générale des Chemins de fer*, 1894.

Clamer, *Journ. Franklin Inst.*, 1903, vol. clvi.

Dudley, *Revue générale des Chemins de fer*, 1893.

Goodman, *Engineering*, 21st September 1906.

Salomon, *Bulletin de la Commission internationale du Congrès des Chemins de fer*, 1896.

CHAPTER XIII.

ALUMINIUM ALLOYS.

WITH the introduction of electrical methods of reducing aluminium, and the consequent production of the metal in quantities and at a price sufficiently low to bring it within the sphere of practical utility, attention was directed to the alloys of aluminium with the object of finding light alloys which would be stronger and more easily worked than the pure metal. These attempts, however, have not met with very marked success, and few of the light aluminium alloys have proved of any industrial value. The reason of this is to be found in the fact that aluminium unites with most of the common metals to form definite chemical compounds which crystallise out in a matrix of practically pure aluminium, and we know that alloys with conglomerate structures of this description are only useful in special cases. Such compounds are formed with iron, copper, nickel, antimony, and tin. Zinc, magnesium, and manganese, on the other hand, form solid solutions with aluminium, and the alloys of these metals are of some importance.

Alloys of Aluminium and Zinc.—The constitution of these alloys has been studied by Heycock and Neville and latterly by Shepherd, whose freezing-point determinations are represented in the curve shown in fig. 43. The microscopical examination of the alloys confirms the evidence of the freezing-point curve, and shows that at one end of the series the alloys containing less than 50 per cent. of zinc are single homogeneous solid solutions; and, at the other end of the series, those containing less than 4 per cent. of aluminium are also homogeneous solid solutions. Between these limits there is a eutectic containing 5 per cent. of aluminium,

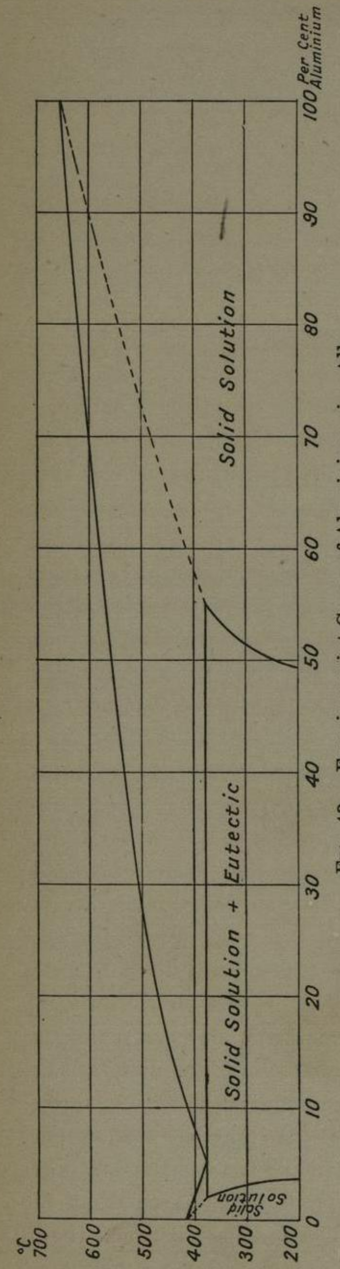

FIG. 43.—Freezing-point Curve of Aluminium-zinc Alloys.

which solidifies at 380°. The alloys with which we are concerned at present are the solid solutions containing less than 50 per cent. of zinc. Those containing up to 15 per cent. of zinc are soft enough to be rolled or drawn, while beyond this amount the alloys are hard and more suitable for castings, as they are easily worked. An alloy of this description is manufactured by Carl Zeiss of Jena, and is known under the name of **Ziskon.** Cast in sand, it has a specific gravity of 3·4 and an ultimate tensile strength of 11 tons per sq. in. and is largely used for parts of scientific instruments where lightness and a considerable degree of strength are required. As regards its hardness and the ease with which it can be worked it is somewhat similar to bronze.

A soft alloy with properties similar to that of brass as regards working is also made by Zeiss of Jena, and is known under the name of **Zisium.** This alloy contains a very much smaller percentage of zinc, together with small quantities of tin and copper. It is lighter than Ziskon, having a specific gravity of 2·95, but has a tensile strength less than half that of Ziskon, namely, 5 tons per sq. in. Perfect screw-threads can be cut on the alloy, and it is used in parts of instruments where a certain amount of ductility rather than strength is desirable.

When more than 25 per cent. of zinc is alloyed with aluminium the metal becomes extremely hard, and both Durand and Richards state that an alloy containing 33 per cent. of zinc resembles tool steel in hardness and has a specific gravity of 3·8.

The alloys of aluminium and zinc containing varying quantities of zinc are now very largely used in the automobile industry, where light castings are of the first importance.

Magnalium.[1] — Alloys of aluminium and magnesium were prepared by Wöhler as long ago as 1866, and by Parkinson in 1867. The latter observes that "none of the magnesium-aluminium alloys promise any practical service in the arts." Unfortunately, both these experimenters appear to have chosen alloys with high percentages of both metals, and it was left to Dr Mach to discover that small percentages of magnesium improve to a very marked degree the mechanical properties of aluminium. Dr Mach experimented on alloys containing 10 per cent. of magnesium; but magnesium is an expensive metal, and, as a matter of fact, commercial magnalium contains very much less than this amount. The cost of an alloy containing 10 per cent. of magnesium would be, for all ordinary purposes, prohibitive.

Boudouard has determined the freezing-points of the aluminium-magnesium series, and his results indicate the existence of two compounds corresponding to the formulæ $AlMg$ and $AlMg_2$. The existence of these compounds is confirmed by the microscopical examination, and they have also been isolated by chemical means; but it is interesting to note that the microscopical examination reveals another compound corresponding to the formula Al_4Mg, which has also been isolated by chemical means, although its existence is not even suggested by the freezing-point curve. It may be that this is yet another example of mutual solubility or isomorphism of a compound with a metal.

As regards the general properties of the alloys, those containing more that 15 per cent. of magnesium at one end of the series and those containing more than 15 per cent. of aluminium at the other are all brittle, the maximum brittleness being reached with

---

[1] Patented 1898, No. 24,878.

the alloy containing 50 per cent. of each metal, which can be crushed between the fingers.

It has already been stated that commercial magnalium contains only a small percentage of magnesium, and, although a large number of alloys are manufactured and sold under the name of magnalium, few of these, if any, appear to contain more than 2 per cent. On the other hand, they all contain a variety of other metals, more especially copper, tin, nickel, and lead.

The importance of magnesium as a deoxidiser must not be overlooked, for it is even more readily oxidised than aluminium; and its beneficial influence on aluminium is in no small degree due to its power of freeing that metal from dissolved oxide.

The three magnalium alloys most commonly used in this country are described by the makers as X, Y, and Z. Of these, X is intended solely for castings where strength is of primary importance; Y is used for ordinary castings; and Z is intended for rolling and drawing.

As regards alloy X it has been stated by Barnett that it contains 1·76 per cent. copper, 1·16 per cent. nickel, 1·60 per cent. magnesium, and small quantities of antimony and iron. Photographs 36 and 37 show the micro-structure of this alloy.

Alloy Y is somewhat similar in composition, except that it contains no nickel, but small quantities of tin and lead.

Alloy Z contains 3·15 per cent. of tin, 0·21 per cent. of copper, 0·72 per cent. of lead, and 1·58 per cent. of magnesium.

The tensile strength of ordinary castings with alloy Y varies from 8½ to 10 tons per sq. in., and that of rolled samples of alloy Z varies from 14 to 21 tons per sq. in.

The alloys work well, and excellent screw-threads can be cut. The speed of working is about the same as that of brass, and the tools should be lubricated with turpentine, vaseline, or petroleum. Alloy Z is exceedingly ductile, and can be spun and drawn into the finest wires. For these operations vaseline or a mixture of 1 part stearine and 4 parts turpentine has been found suitable. In drawing tubes or wire the alloy must be annealed by heating and cooling suddenly. Slow cooling produces hardening.

For rolling, magnalium should be heated to a temperature of 350°, and the temperature of the rolls kept at about 100°. Annealing should take place after every second pass.

With regard to the casting of alloys X and Y, the metal should be melted at as low a temperature as possible (about 660°) under a layer of charcoal, and the scum carefully removed before pouring. In making the mould the sand should not be rammed so closely as for brass castings, and it is recommended to mix the sand with a tenth part of meal in order to allow free escape of gases. The facing of the mould should be treated with blacklead, French chalk, or petroleum and lycopodium powder. Metal moulds are also suitable, if polished with blacklead.

Magnalium contracts considerably on cooling (from 2 to 4 per cent.), and to insure good castings it is necessary to have a good head of metal and large gates and runners.

Magnalium can be soldered, but the operation is difficult on account of the high conductivity for heat of the alloy as well as the difficulty of obtaining a surface free from a film of oxide.

Magnalium is very little affected by dilute acids, and can be employed with perfect safety for the manufacture of cooking utensils and all culinary appliances.

It is evident that magnalium is eminently suitable for a great variety of purposes, and there is no doubt that its price alone prevents it being more widely used.

Aluminium-Copper.—Alloys of aluminium and copper are used to some extent; but only those containing 6 per cent. or less of copper are of any industrial value. These alloys have been used in naval construction, particularly in France; and in 1894 a torpedo-boat was built in this country by Messrs Yarrow and Co. for the French navy, in which the hull was composed of an alloy containing 94 per cent. of aluminium and 6 per cent. of copper. The excessive corrosion of this alloy by sea-water, however, has effectually prevented any further trials. In the automobile industry alloys containing 3 to 5 per cent. of copper are sometimes used.

With regard to the constitution of the alloys, the freezing-point curve of the entire series has been given in fig. 32, and it is only necessary to say that the addition of copper to aluminium gives rise to a hard eutectic consisting of aluminium and the compound Al_2Cu, which freezes at a temperature

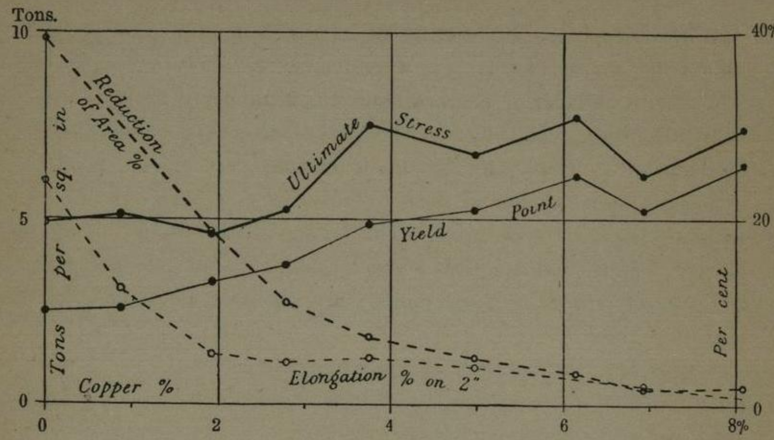

FIG. 44.—Tensile Tests on Sand Castings.

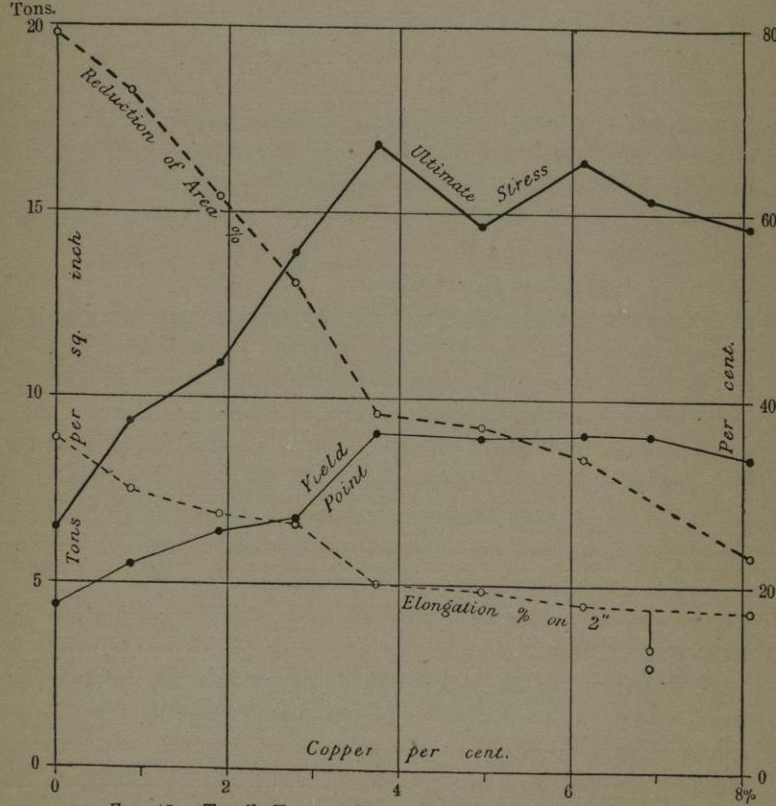

FIG. 45.—Tensile Tests on Bars rolled down to $1\frac{1}{4}$ in. diameter.

slightly below 550° and separates between the crystals of pure, or practically pure, aluminium. The compressive strength is therefore increased, and the alloys are more easily worked than pure aluminium.

The curves in figs. 44, 45, and 46 are plotted from the results of tests by Carpenter and Edwards and show the mechanical properties of the alloys in the form of sand castings, rolled bars, and cold-drawn bars respectively. From these results it is evident that there is no advantage in adding more than 4 per cent. of copper, as beyond this point there is a decrease in ductility without any corresponding increase in tenacity. The alloys do not contract on cooling more than aluminium, and they appear to

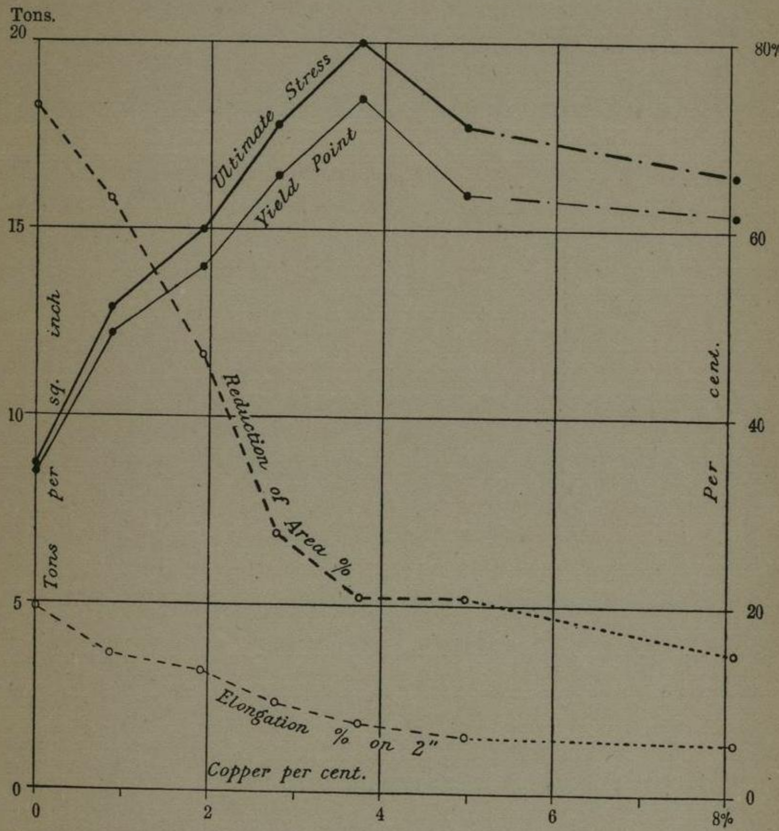

FIG. 46.—Tensile Tests on Bars Cold-drawn.

be practically unaffected by heat treatment below the melting-point of the eutectic. Figs. 47, 48, and 49 show the results of tests on chill castings and also on sand castings slowly cooled and quenched from 450°.

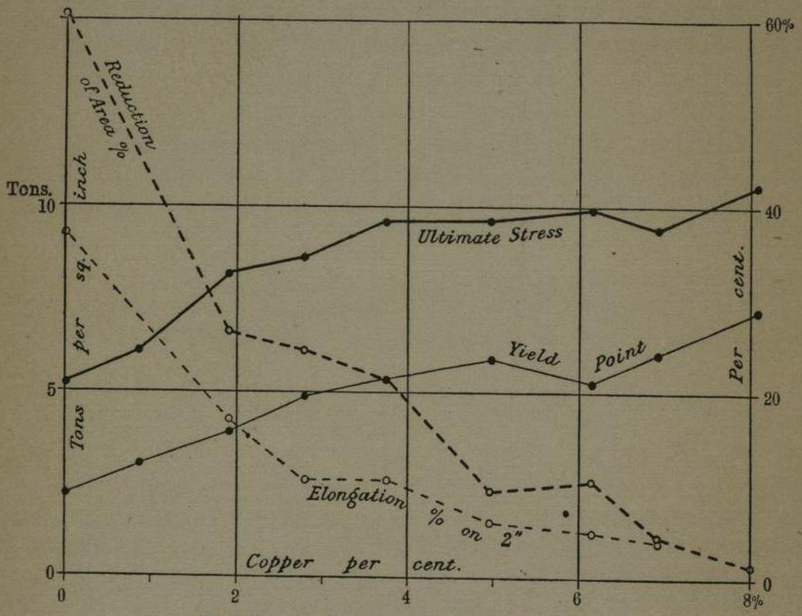

FIG. 47.—Tensile Tests on Chill Castings.

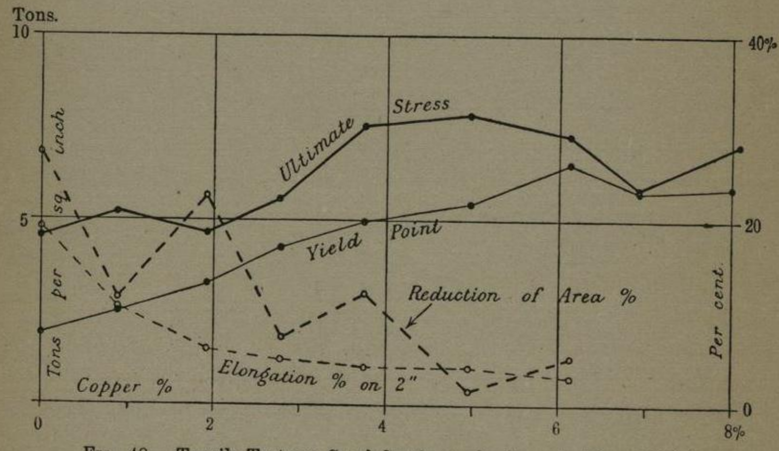

FIG. 48.—Tensile Tests on Sand Castings, slowly cooled from 450° C.

An alloy under the name of Partinium has been found on analysis to contain aluminium 88·48, copper 7·36, zinc 1·67, silicon 1·14, and iron 1·31 per cent.

Aluminium and Nickel.—Nickel is sometimes added to aluminium as a hardening agent in place of copper. It is unnecessary to consider the constitution of the nickel-aluminium series in detail, as only those alloys at the extreme end of the series are of any practical value. These alloys contain less than 5 per cent. of nickel, and consist of crystallites of a brittle compound, corresponding to the formula $NiAl_6$, embedded in practically pure aluminium.

The effect of nickel on aluminium is therefore very similar to that of copper. Occasionally nickel and copper are both added to aluminium, but it is doubtful whether any advantage is derived from this procedure.

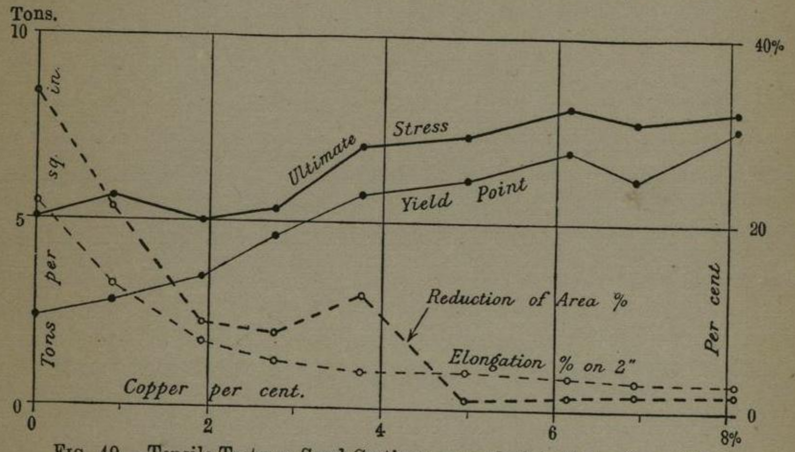

FIG. 49.—Tensile Tests on Sand Castings, quenched in Water from 450° C.

Aluminium and Manganese.—Up to the present the alloys of aluminium and manganese have not received the attention they deserve; but they are exceptionally interesting from a theoretical point of view, on account of their magnetic properties, and it is possible that they will be made use of in the arts. The only alloys which appear to have been put to any practical use are those containing 2 or 3 per cent. of manganese, which have lately been used in the automobile industry. With less than 10 per cent. of manganese the alloys consist of a solid solution, and the addition of the manganese has the effect of increasing the tensile strength of the aluminium. Beyond 10 per cent. the alloys become very hard and brittle.

BIBLIOGRAPHY.

Barnet, *Journ. Soc. Chem. Ind.*, August 1905.
Boudouard, *Bulletin de la Société d'Encouragement*, November 1901.
Carpenter and **Edwards**, "Eighth Report Alloys Research Committee," *Inst. Mech. Engineers.*
Richards, *Aluminium.*
Shepherd, *Journ. Phys. Chem.*, vol. ix.

CHAPTER XIV.

SILVER AND GOLD ALLOYS.

Silver Alloys.

THE alloys of silver with copper may alone be said to have any important industrial applications. From time to time many other silver alloys have been suggested; but none of them have taken the place of the well-known silver-copper alloys. The importance of these alloys may be realised when it is remembered that the average weight of standard silver articles, hall-marked at the Assay Offices of Birmingham, Sheffield, and Chester alone, during the last five years amounts to 6,037,214 oz., or nearly 225 tons; and it has been estimated that the amount of standard silver melted annually in the United Kingdom is close on 700 tons.

The constitution of the silver-copper alloys has been thoroughly investigated by Roberts-Austen and Heycock and Neville, and the results of their researches are plotted in the freezing-point curve shown in fig. 50.* It will be seen that the metals form a simple series of alloys with a eutectic containing 71·9 per cent. of silver and melting at 778°. This is the alloy which Levol in 1854 considered to be a definite compound on account of its remarkable homogeneity.

The alloys of industrial importance are few in number, and contain not less than 80 per cent. of silver. The following table shows the composition of the silver standards used for coin and for plate in different countries:—

---

* The extent of the line representing the eutectic has not been accurately determined, but it should be much longer than that shown in the diagram.