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Upon the Structure of Metals and Binary Alloys.

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(Continued from p. 16.)

Fig. 10 shows the surface-structure of a bar of aluminium. Two intersecting dendrites are seen. In each only one quadrant has developed. We have two axes at 90° , and from each grow parallel branches normal to their own axis, but parallel to the adjacent axis. From these branches grow leaf-like grains, thus forming a true skeleton crystal. The whole shows a decided cubic character. The cubic structure of aluminium can be clearly shown by casting a small ingot of the metal. When half solid, the ingot is tilted and the liquid part is allowed to drain off. The rough surface thus exposed is seen to be divided up into many areas; each area is made up of a number of small cubes similarly orientated, whilst each cube is made up of row upon row of minute grains. The whole structure resembles a surface of silicon steel ($4\frac{1}{2}$ per cent.) in Stead's Crystalline Structure of Iron and Steel.*

Copper, platinum, gold and silver show this dendritic structure on their surfaces when suitably cooled. *Fig. 11* shows the structure met with on the surface of a cupellation button of silver. Only the center of the skeleton crystal is shown, but the two main axes can be seen at right angles to each other; from each grow out, normally, parallel rows or branches composed of grains. The nearer to the center of crystallization, the smaller are the grains. In *Fig. 12* a smaller skeleton crystal is shown. It is similar to the large ones, but is stunted in growth. It shows the curious growth at the ends of the axes where they merge into the

* *Iron and Steel Institute*, May, 1898.

surrounding surface. Although these skeleton crystals are fairly common, they do not occur on all silver buttons. The normal structure of the surface of a cupellation button of silver is shown in *Fig. 13*. It consists of grains with straight boundaries. This structure is probably the result of contraction on solidification, because, in places, the lines are seen to cut across patches of similar orientation, *i. e.*, crystals. The true area of each grain (crystal) is seen by its orientation, and the lines of fissure generally coincide with the true grain (crystal) boundary because these will be the lines of weakness. In some cases, however, they take a direction of their own. This cooling structure is probably similar to that met with in many basalts. The surface structure of a silver ingot is seen in *Fig. 14*. There are several large grains or crystals with irregular boundaries but distinct orientation, each made up of secondary grains, similarly arranged, causing that orientation.

In the case of bismuth, *Fig. 15*, we see that the dendrites are inclined to assume a definite crystalline form; and this is exactly what we should expect when we remember the definite forms seen on a crust from a crucible of bismuth. The stars of antimony are too well known to require any description here.

When certain metals are cast, dendrites are formed by the shrinking of the liquid part during solidification, thus leaving them standing above the surface. A similar thing occurs when many alloys are cast. We may have dendrites of a metal left in relief, due to the shrinking of the eutectic or portion of the alloy which solidifies last; or we may have definite crystals, generally of a compound, standing up above the surface. These surface structures, as we said before, are often very reliable indications of the internal structure of the alloy. They may also be very misleading, however, as in the case of the bronzes between 70 per cent. and 95 per cent. of copper.

In his paper on the "Crystalline Structure of Iron and Steel,"* Stead points out that the same law which deter-

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mines the size of the individual crystals formed when hot saturated solutions of chemical salts are cooled quickly or slowly holds good when metals solidify from the liquid state. If a metal be cooled very slowly past its freezing point, its structure will be comparatively large; if it be cooled rapidly past its freezing point, the result will be a much finer or more minute structure. In cooling slowly, crystals start to grow from a comparatively few points only, and the resulting structure is large; in rapid cooling, the points of initial crystallization are numerous, and the structure on complete solidification is small. When a crystal starts from a point it grows in all directions till interfered with by the growth of adjacent crystals. As the crystals seldom grow so that their crystallographic axes lie in the same directions, we find on solidification that each has a different orientation. This difference in orientation is beautifully seen if we take ingots of lead, tin, cadmium, zinc, etc., and lightly etch their surfaces. The effect of etching is to take off the surface of the metal, but not as a film of uniform thickness. The acid has not the same effect on each crystal, but removes more of one than of another, the amount depending upon the position of the crystal with relation to the surface which is being etched. The acid follows the track of the secondary crystals, or rather grains, and so we have a step-like surface eroded, which resembles, more or less, a broken surface of galena. Thus, light is more or less reflected from each crystal, depending on the angle at which the step-like surface is inclined.

The size of the crystals of an ingot of metal and, to a great degree, their shape depend upon the mould in which the metal is cast. Thus tin, when cast in a stone mould, gives quite a different appearance to what it does when cast in iron; the difference, of course, being due to the difference in rate of cooling. Again, the size of grain or crystals depends upon the purity of the metal used. If pure and impure tin be cast in the same mould, in the case of the impure tin the crystals will be comparatively long and slender, their length pointing towards the axis of the ingot.

The fractures of ingots in general reveal a columnar

structure. If an ingot of zinc be broken, elongated crystals with irregular faces are seen to have grown from the surface next to the mould perpendicularly towards the center of the ingot. If a section of an ingot of lead or tin be cut vertically, polished and etched, a similar structure is seen. If ingots of lead are broken hot, this columnar structure is beautifully revealed, whilst cast cylindrical rods of most metals show a radial structure, due to the same cause. On fracturing a cast rod of antimony the structure is that of numerous elongated pyramids with their apices meeting at the axis of the rod, their bases forming the cylindrical surface of the rod.

THE EFFECTS OF STRAIN.

The effects of strain upon metals has been well explained and illustrated microscopically by Ewing and Rosenhain.* Charpy† has illustrated the effects of strain and also of annealing upon the brasses, etc.; Roberts-Austen‡ upon steel rails and gun tubes.

Ewing and Rosenhain state that no effects of strain can be detected under the microscope within the elastic limit; but as soon as this is passed, fine dark lines are seen on the faces of the grains. They are more or less straight, are parallel in each grain, but are differently orientated in different grains. The first lines that appear are those approximately transverse to the line of force; but as the force increases, other systems of lines appear on other grains, and these lines are inclined to the direction of straining. As the straining increases some of the grains begin to show one, two, three and more systems of parallel lines, thus giving the grain the appearance of Schillerization. If the surface of a bar of bismuth, which has been strained till it broke, be examined, the lines or slip-bands are clearly seen on each side of the fissure. Several parallel groups will appear in view. *Fig. 6* in Dr. Mathews' paper showed some of these

* Bakerian Lecture, May 18, 1899, *Phil. Trans. Royal Soc.*, cxci, p. 353.

† *Bull. de la Soc. d'Encouragement*.

‡ *Journal Iron and Steel Institute*, No. II, 1898; No. II, 1900.

slip-bands in tin. It shows the strained surface of an ingot of pure tin, whilst *Fig. 5* of the same paper showed lines of strain set up in a section of tin which had been hammered and then annealed. Similar slip-bands in crystals of cadmium are shown in *Fig. 8*. The cry of tin, the crackling of zinc, etc., are due entirely to the formation of these slip-bands.

It was mentioned above that when a soft metal, such as lead or tin, was cut with a file, particles tend to cling to the file and tear the surface of the metal. A similar thing happens with nearly all the softer alloys. The immediate effect is not noticed; but on etching, long parallel lines of irregular grains or crystals are seen to have been developed. *Fig. 3* shows such lines developed in tin. When a soft metal or alloy is cut with a saw, a similar crystallization is set up, and unless the metal thus modified is removed during subsequent treatment, this crystallization appears along with the original structure on etching. *Fig. 4* shows a section of slowly cooled tin which has been cut with a saw; a finer crystallization is seen together with the larger structure, due to the original cooling. If etching be prolonged the finer structure is obliterated, showing that it is only on the surface.

Now, when a piece of metal is hammered or rolled the crystals become lengthened in the direction in which it has become drawn out, and shortened in the direction of contraction. In the case of copper, iron and other of the tougher metals, this attenuating stage is of comparatively long duration; but in the case of the softer metals it is short and the crystals or grains break up to form a new and minute crystallization. *Fig. 2* of Dr. Mathews' paper shows the appearance of hammered tin. The structure is roughly granular and no trace of the original slow-cooling structure can be seen as in *Fig. 4*. Rolled tin has a similar structure, and it is curious to note that the thinner the piece is rolled the more distinct become the individual crystals. At a certain point they no longer split up, but become attenuated as if plastic. The structure of rolled cadmium is shown in *Fig. 6*.

THE EFFECT OF HEAT-TREATMENT.

It is well known that annealing tends to relieve the strain in a metal or alloy. In many metals it does more than this; it causes the growth of crystals or grains. *Fig. 1* of Dr. Mathews' paper shows a bar of tin rolled out to about 3·5 millimeters thick. The right-hand pair show the structure of the metal just as it comes from the rolls. The left-hand pair have been annealed for ten days upon a hot-plate at not more than 180° C. The size is slightly reduced. The difference between the unannealed and the annealed specimens is striking to say the least. The orientation in the left-hand pair is marked and shows the boundaries between the various crystals. *Figs. 3* and *4* of the same paper show hammered tin unannealed and annealed at about 180° C. for seven days on a hot-plate (not ten days as stated). Again the difference between the two specimens is striking. In *Fig. 4* it will be noticed that the new crystals tend towards straight regular boundaries and in section are more or less perfect hexagons.

Fig. 5 shows five pairs of strips of cadmium rolled out from a rod. Starting from the right, the first pair have a thickness of 0·075 inch, the second of 0·049 inch, the third of 0·036 inch, the fourth of 0·024 inch, whilst the last and thinnest pair are only 0·018 inch in thickness. They were rolled out from a rod having a circular section $\frac{5}{16}$ inch in diameter. Their length is 2½ inches and breadth 0·4 to 0·45 inch.

The right-hand strip of each pair has been annealed for seven days in an air bath at a temperature under 180° C. Etching in all cases was with nitric acid dilute. After rolling, the thickest pair (No. 1) were found to have the coarsest structure and this is shown in *Fig. 6*. After annealing, although tolerably large crystals were found in all of the strips, the thickest strip was found to have the coarsest average grain. *Fig. 7* shows the crystals developed in No. 3 by annealing. The definite boundaries and distinct orientation are to be noted. Those developed in No. 1 were so large that a single crystal would cover the whole figure at the same magnification, whilst those developed in the thin-

9. x 33. v.

10. x 33. v.

11. x 33. v.

12. x 33. v.

13. x 16. v.

14. x 33. v.

15. x 33. o.

16. x 33. v.

17. x 33. v.

18. x 33. o.

19. x 33. o.

20. x 33. o.

21. x 56. o.

22. x 33. o.

23. x 33. v.

24. x 30. v.

25. x 56. o.

26. x 33. v.

27. x 33. o.

28. x 33. v.

29. x 16. v.

30. x 33. v.

31. x 33. v.

32. x 16. o.

nest strip were proportionately smaller. *Fig. 8* shows some of the smaller grains or crystals of No. 1, photographed after the strip had been bent. The strain produced by bending has set up the series of slip-bands. Five distinct parallel series can be seen in the largest grain on the left.

An exactly similar experiment was performed with tin. The annealing was carried on for five days on a hot-plate and the results were identical with those of the cadmium. In both cadmium and tin, annealing produces a marked brittleness, and when the strips are distorted they cry.

If ordinary rolled sheet lead be etched and examined, a structure similar to *Fig. 6* will be met with. Etching is best performed with acetic acid for a long period. Anneal it for a week at a temperature of only 200°C. , and a coarse, very irregular crystalline structure will be developed. The crystals will be of all sizes and shapes; in many, distinct twinning will be observed. In all cases the difference in orientation will be marked. In one case a crystal quite 1 inch long by $\frac{1}{2}$ inch in breadth was grown in five days by the author. The temperature was only 180°C. and the thickness of the sheet of lead 1.75 millimeters.

Take zinc and roll it out into strips; it will take a fairly high power to reveal its structure. Anneal it as before shown and you will find the crystals have grown so large that some two dozen will be all that are able to occupy your strip. The rolled zinc will be exceedingly tough, but after annealing it will crackle on bending ever so slightly and will break if further bent, for annealing has made it extremely brittle. On slightly bending it and then examining it under the microscope, it will be seen that each grain is traversed by parallel systems of slip-bands, which develop into cracks if the bending be carried to any considerable extent.

If the surface of electrolytically deposited copper be examined, a coarse crystalline structure is seen. On parts of the sheet it will often be found that the rate of deposition has been greater than the surrounding surface and a crystalline knob of copper stands out above the level of the rest of the sheet. If a section be made through one of

these knobs, and the surface be polished and etched, the true crystalline structure is shown up. It consists of comparatively large, irregular crystals, each possessing a definite orientation. If this copper be rolled out, the large crystals are broken up and a much finer crystallization is set up, still composed of crystals with irregular boundaries. If copper foil be examined after its repeated annealing and rolling, or rolling alone, it is seen to be composed of very small grains. The foil possesses a marked amount of spring. No amount of etching will show any orientation and the structure seems to be composed entirely of oval grains, pointing, of course, in the direction of rolling. It is similar to that of sheet-copper which has been rolled out from an ingot. Anneal it for a moment at a straw heat and it becomes quite limp with no trace of spring left. On examination the fine crystalline structure has disappeared and a large mottled structure is now seen. Thus there is an intimate relation between the fine rounded or oval-grained structure and elasticity of the copper foil.

Electro-nickel when polished and etched shows a reniform structure where it has formed a knob-like mass. Numerous distinct layers can be seen, but, so far, no distinctly crystalline structure can be seen. The structure of iron appears to be similar to that of nickel, that is, it consists of layer upon layer like an agate. The effects of annealing and rolling electro-nickel and iron have not been examined as yet by the author.

The growth of crystals in the solid due to annealing has been shown over and over again. Roberts-Austen, in his last Cantor Lectures, delivered to the Society of Arts, London, exhibited three photomicrographs showing the growth of crystals in pure gold. The first showed two plates of pure gold pressed together. The squeezing was so great that the crystals had been strained. Without strain, it is thought that no welding will take place. The second view showed the plates after annealing at 750° C. and slowly cooling. The junction between the two plates could be distinguished, but in several places crystals had grown across the junction. A third view showed the same after long

annealing and the line of junction had entirely disappeared. If a section be taken across a weld in a steel rail or bar which has been joined by the Goldschmid welding process, no line of junction can be seen.

ALLOYS.

Under the heading of "Alloys as Solutions," Dr. Mathews points out that certain metals when liquid at ordinary temperatures do not mix or alloy, and on standing separate into two layers, the heavier at the base.

The following are some of Dr. Alder Wright's figures, obtained by taking each of the five pairs well mixed by stirring, and then allowing them to stand molten for some hours at 800° C.; separation took place; two liquid alloys were formed; these were quenched and each analyzed.

In the case of zinc and lead, the heavier alloy contained 1.3 per cent. Zn; the lighter 1.57 per cent. of Pb.

In the case of zinc and bismuth, the heavier alloy contained 14.28 per cent. Zn; the lighter 2.32 per cent. of Bi.

In the case of aluminium and lead, the heavier alloy contained 0.07 per cent. Al; the lighter 1.91 per cent. of Pb.

In the case of aluminium and bismuth, the heavier alloy contained 0.28 per cent. Al; the lighter 2.02 per cent. Bi.

In the case of aluminium and cadmium, the heavier alloy contained 0.22 per cent. Al; the lighter 3.39 per cent. Cd.

If we allow our molten metal to cool down very slowly till it solidifies, and then examine the two alloys thus formed, in the case of zinc and lead or aluminium and lead, and most probably also of aluminium and bismuth or aluminium and cadmium, we get the same results. Each alloy is a solid solution of one metal in the other; no crystals but those of the metal in excess can be seen. Take the aluminium-cadmium pair. The structure of the upper part is that of aluminium, and all of the cadmium it contains is in solid solution. The structure of the base is that of cadmium, and all the aluminium in it is in solid solution. In the case of the lower alloy of the lead-aluminium pair, it is probable that the lead throws all of the aluminium out of solution before solidification, because, according to

Heycock and Neville, the freezing point is not depressed at all.

With the zinc-bismuth pair matters are different. The upper alloy shows zinc containing all the bismuth in solid solution, but the lower one shows a fine crop of crystals in a groundmass, which is probably a eutectic of bismuth and zinc, as is shown in *Fig. 16*. Thus between bismuth and about 13 per cent. Zn, 87 per cent. bismuth, we get one layer in each alloy we make. Between these points we have a simple series of alloys, whose freezing-point curve consists of two branches inclined to each other and meeting at the eutectic point 3.5 per cent. Zn at about $240^{\circ}\text{C}.$ *

If either of the five pairs of metals above be melted and a sufficient proportion of either tin, silver, antimony or copper be added, no separation will take place; but if the quantity of the "solvent" metal is less than a certain amount, the alloy separates into two layers, each layer consisting of a ternary alloy of the three metals. *Fig. 17* shows a case where sufficient of the "solvent" metal was added and a single ternary alloy was formed. The alloy consists of equal weights of zinc, bismuth and tin. The figure shows long dendrites, which closely resemble those of zinc in zinc-tin alloys, set in a groundmass, probably a triple eutectic of BiZnSn.

In many text-books the amounts which each of the above pairs of metals retain of the other when solid varies widely. In some cases we are told that aluminium mixes freely with both bismuth and cadmium. The reason for this lies in the method of cooling. If instead of cooling slowly we cast or chill our alloy, directly after stirring, we don't allow our emulsion to settle, and in consequence *globules* of the heavier are found in the lighter alloy. *Fig. 18* shows the surface of aluminium containing such globules. Aluminium was melted with some Bi and Cd. When thoroughly melted the pot was shaken and the alloy poured into a cold iron mould. In consequence of the rapid cooling, separation

* Gautier: *Bull. de la Soc. d'Enc.*, Vol. I, 1896, p. 1293. Roberts-Austen: "Introduction to Metallurgy," plate pp. 114-115.

could not take place, and scattered throughout our aluminium appear shots or globules of the bismuth-cadmium alloy. When slowly cooled perfect separation took place.

BINARY ALLOYS.

Charpy* has published one of the most complete papers on the microstructure of binary alloys. He classes them according to their curves of fusibility, following Le Chatelier.

Group I.—Two branches of curves starting from the melting-points of the two pure metals and meeting at a point corresponding to the eutectic alloy; this curve is obtained when the metals form neither definite compounds nor isomorphous mixtures.

Group II.—Three branches of curves, two of them starting from the melting-points of the pure metals and a third exhibiting a maximum and crossing the two former in two points corresponding to two eutectics; it is the case of two metals forming a definite combination.

Group III.—The curve of fusibility is continuous and unites the melting-points of the two metals forming isomorphous mixtures.

Fig. 14 in Dr. Mathews' paper shows types of these curves. Group I is represented by the AgCu curve, Group II by the SbCu curve, and Group III by the AuAg curve.

To Group I belong all those alloys in which the excess of either metal crystallizes out in a eutectic which is a mechanical mixture of the two metals.

Tin and zinc.

Tin and lead.

Tin and bismuth.

Lead and antimony.

Lead and silver.

Zinc and aluminium.

Copper and silver.

Copper and gold.

Dr. Mathews' explanation of *Fig. 18* of his paper holds good in the case of all the above alloys, the only difference being that in some cases the compositions *b* and *d* represent comparatively large figures, as for example in the case of copper and silver or copper and gold; in some cases *b* and *d* represent compositions of solid solutions infinitely dilute;

* *Bull. Soc. d'Encourag.*, March, 1897.

that is, b and d are numerically very small, as in the case of tin and zinc, etc.

We can form a sub-group in which the excess of one metal crystallizes out in a eutectic which is a solid solution of this metal in the second.

Aluminium and tin.

In Group II we get two divisions for each pair of metals alloyed, each division being comparable with Group I, thus:

(1) The excess of the first metal or the compound crystallizes out in a eutectic which is a mechanical mixture of this metal and the compound.

(2) The excess of the second metal or the compound crystallizes out in the second eutectic, which is a mechanical mixture of the second metal and the compound.

Copper and antimony.

Tin and nickel.

A sub-group might be formed in which the eutectics are solid solutions of the compound in either the first or the second metals.

Antimony and aluminium.

Thus we get two divisions, each of which is comparable with the sub-group of Group I. In the case of antimony and aluminium we have the compound SbAl crystallizing out in a eutectic which is a solid solution of Sb in Al, or in a eutectic which is a solid solution of Al in Sb.

[To be concluded.]

ARC LAMP CARBIDE ELECTRODES.

A patent granted May 20th to Robert Hopfelt, of Berlin, Germany, describes several forms of a new type of electrode for arc lamps. In each case the material of the electrode consists of calcic carbide, coated with a water-proof compound or sheathed with a metal such as aluminium. It is stated that metallic carbides, such as calcium carbide, gives a much more powerful arc than do ordinary carbon electrodes, but that this material has not been employed in arc lighting heretofore because of the decomposition incident to the presence of moisture in the air. By covering the surface of the carbide with a layer impervious to moisture, it is claimed that this objection is obviated. In another form of the electrode there is a cone of metallic wire, and in still another form, a core of carbon dust. A solid electrode is also described, consisting of a mixture of carbon and carbide.—*Electrical World*.