TITANIUM AND TITANIUM ALLOYS

PART III

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The very great effect of small amounts of impurities—oxygen, nitrogen and hydrogen, as well as of carbon, silicon and metallic elements—on the characteristics of titanium is very clearly shown when a comparison is made between the mechanical properties of samples of the metal prepared by various methods.

The purest titanium that has yet been produced is undoubtedly that made by the iodide process. This is reported to contain 0.01 to 0.05 per cent each of silicon, iron, aluminium, and calcium, rather less magnesium, manganese, nickel and copper, and rather more molybdenum. In addition, Gonser,* of the Battelle Memorial Institute, states that the carefully prepared soft metal contains 0.02 to 0.03 per cent of carbon and 0.002 to 0.003 per cent of nitrogen (with occasional samples running up to 0.009 per cent). It is believed that the content of oxygen is less than that of nitrogen. This material, made under the best conditions, has a Vickers hardness of about 60 and a tensile strength of about 14 tons/in.^{2} with an elongation on 2 in of 55 per cent. (Under less carefully controlled conditions, contamination may cause the hardness to rise to 115 Vickers.)

Physical Properties

When this metal is arc-melted in argon in a water-cooled copper crucible, the tensile strength is reported as 17-21 tons/in.^{2}. The effects of possible contamination by tungsten from the electrode, by copper from the crucible, and by oxygen and nitrogen before, as well as during melting, are evidently making themselves apparent. Metal which is melted in a graphite crucible, as produced by the Remington Arms Co., is very much harder and less ductile ; and Bradford, Catlin, and Wemple report that this material (containing 0.3 per cent of carbon) has a tensile strength of 50 tons/in.^{2}, a 0.2 per cent yield value of 42 tons/in.^{2}, and an elongation on 2 inches of 32 per cent. Titanium made by magnesium reduction and consolidated by powder metallurgy methods is said to have a tensile strength of about 35 tons/in.^{2} and an elongation on 2 inches of 25 per cent. The range of properties—in material all of which would be considered as commercially pure—extends from those of a metal about as soft as pure copper to one as hard as a constructional steel.

It is evident that one of the most pressing needs in developing the technique of titanium and its alloys is that precise information should be collected on the effects of oxygen, nitrogen, hydrogen and carbon on the properties of the metal. Preliminary work on this problem has, in fact, been undertaken at the Battelle Memorial Institute and some of the results obtained are quoted by Howard C. Cross. In the past, no quantitative measurements of the effects of the gases have been attempted, partly because of the lack of titanium pure enough to serve as a base-line material, and partly because no reliable chemical methods exist for the determination of these gases—particularly oxygen—in titanium. With the advent of relatively large supplies of iodide titanium, the

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first difficulty no longer exists ; and the second was overcome by measuring the quantities of the gases actually introduced into the metal. " Alloys of titanium," Cross writes " with oxygen, nitrogen, or hydrogen, were made at Battelle by adding known volumes of the gases to an evacuated system within which wire specimens of iodide titanium were suspended. The wire was heated to between 700° and 1,000°C for the time interval required to obtain absorption of the gases by the metal, and the uniform diffusion of the gases throughout the metal. Absorption of oxygen was rapid and complete. With hydrogen, the specimen temperature had to be lowered to between 650 and 700°C to obtain complete absorption. Nitrogen diffused so slowly that, after complete absorption, specimens were heated to 1,100°C for homogenization."

Effect of Gases

Hardness measurements reported on this material indicate that oxygen and nitrogen harden titanium to about the same extent, the addition of one atomic per cent of each increasing the hardness from about 115 to about 250 Vickers. It is noted that " oxygen refines the structure of titanium, making the plates of alpha-titanium smaller and the Widmanstätten arrangement more regular. Nitrogen promotes the formation of needles of alpha-titanium." On the other hand, hydrogen has no significant effect on the structure in amounts up to one atomic per cent (0.021 weight per cent) and does not harden the metal. The tensile strength is increased from about 18 tons/in.^{2} to 38 tons/in.^{2} by one atomic per cent of oxygen and to 53 tons/in.^{2} by the same amount of nitrogen.

Similar exploratory experiments on the effects of oxygen (added as the oxide), nitrogen (added as nitride), carbon, tungsten, molybdenum, and chromium were also made using arc-melted metal prepared from magnesium-reduced or iodide titanium. In this work, gas evolution from the titanium powder sometimes caused considerable spattering which resulted in trouble either through tungsten contamination from the electrode or in ingot defects. These difficulties prevented accurate evaluation of the effect of alloy additions, but made it apparent that quite small additions of the elements that were studied could appreciably harden and strengthen titanium.

Titanium-Nickel

It is admitted that very much more work on alloys of titanium is desirable. One investigation that has been commenced is concerned with the titanium-nickel system, and J. R. Long has reported preliminary results on alloys prepared from powders either by the conventional methods of powder metallurgy or by sheath rolling. All the alloys produced are believed to contain 0.1 to 0.2 per cent of oxygen, and the results are presented as a vertical section through the titanium-nickel-oxygen system. There is a eutectic melting at about 960°C with 33 per cent of nickel between titanium and a body-centred cubic intermetallic compound (with 41 per cent of nickel and melting at about 1,075°C). It appears that the body-centred form of titanium can dissolve up to 12 per cent of nickel in solid solution, but that less than 0.5 per cent of nickel will dissolve in the low-temperature hexagonal alpha modification of titanium. There is thus a strong resemblance between the titanium-nickel and iron-carbon diagrams ; and the alloys, in fact, can be heat-treated to yield martensitic and other structures found in steels.

An investigation is also under way at the Ohio State University Research Foundation, Columbus, Ohio, on titanium-chromium alloys made by induction melting in low-porosity beryllia or thoria crucibles, as well as by arc melting. Tensile properties on a large number of alloys with beryllium, boron, aluminium, indium, silicon, zirconium, vanadium, molybdenum, and manganese, made by powder metallurgy methods, have been surveyed by Larsen, Swazy, Busch, and Freyer, of P. R. Mallory & Co., Indianapolis ; and Brace and Hurford, of Westinghouse Electric Corp., Pittsburgh, Pa., have reported creep-rupture and constant strain (0.5 per hour) tests at high temperatures on induction-melted alloys containing 20-40 per cent of chromium with added elements. It is evident that a great amount of rapid survey work is proceeding in America in the field of titanium alloys ; but it would seem that there is an even more urgent need for detailed and thorough study of the basic alloy systems.