# TITANIUM AND TITANIUM ALLOYS

## PART I

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Melting at a temperature of about 1,725°C., extraordinarily resistant to corrosion at room temperatures to sea-water, to most mineral acids, to all industrial atmospheres, and probably to stack and flue gases in any concentration, and with a density of only 4.5 gm/cc (a little more than half of that of steel) titanium is an unusually attractive metal. Its possibilities have fired the imagination of many metallurgists and engineers in recent years, and at the end of last year the work now in progress in America on what may be termed the industrial metallurgy of titanium was described at a Symposium on Titanium sponsored by the Office of Naval Research.*

TABLE I

COMPARISON OF TITANIUM WITH OTHER COMMON METALS

| Metal | Melting point | Thermal expansion per °C. | Young's Modulus lb/sq. in. | Density gm/cc. | Tensile strength (lb/sq. in. fully cold worked) | Ratio of tensile strength to density |
|---|---|---|---|---|---|---|
| Titanium ... ... | 1725°C | $8.5\times10^{-6}$ | $16\times10^{6}$ | 4.51 | 130,000 | 28,800 |
| Iron ... ... | 1540 | 11.7 | 29 | 7.87 | 100,000 | 12,700 |
| Nickel ... ... | 1455 | 13.3 | 30 | 8.90 | 115,000 | 12,900 |
| Copper ... ... | 1083 | 16.6 | 16 | 8.96 | 75,000 | 8,400 |
| Aluminium ... | 660 | 23.9 | 10 | 2.70 | 20,000 | 7,400 |
| Magnesium ... | 650 | 25.2 | 65 | 1.74 | 35,000 | 20,000 |

The comparison of titanium with other commoner metals is well set out in Table I. With these characteristics in mind, it is suggested in the first Paper, by N. E. Promisel, of the Bureau of Aeronautics, U.S. Navy Department, that the following are probable applications of titanium in aircraft :—

(i) Substitution for existing parts of aluminium and magnesium alloy because of the high ratio of strength to weight for titanium at room temperatures.

(ii) Substitution for stainless steel and light alloys because of the outstanding resistance of titanium to corrosion, particularly by chlorides. The protection of leading edges in high speed aircraft against surface roughening is a problem which may become of increasing importance, and here titanium may be of service. Titanium may also be of service in naval applications for condenser tubes operating with high water velocities, in light-weight piping systems handling salt water, in pump rods or rotor shafts, in water-lubricated bearings, and even for the wires of shipboard radio aerials which are exposed to funnel gases.

(iii) Substitution for steel where space is at a premium.

* Symposium on Titanium. *Metal Progress*, 1949, 55 (2), 185.

(iv) Use for parts, such as those in de-icing equipment or adjacent to jets, which may in service reach a temperature of 150-200°C., at which the present high-strength light alloys begin to weaken seriously.

(v) Use as a basis for high-temperature alloys, perhaps containing silicon or aluminium to retard oxidation.

(vi) Use for special applications, such as high-speed hot air heater wheels, armour plate, and electrical components.

For similar reasons titanium and titanium alloys may find numerous applications in other branches of the armed services and in industry, and the final remarks of L. S. Foster, of Watertown Arsenal, may be quoted. " To visualize the potentialities of titanium alloys having a high ratio of strength to weight," he writes, " one merely needs to remember that future armies and their equipment must be transportable by air. Only the high cost of titanium and the lack of detailed information about the properties of titanium alloys prevent the large-scale adoption of the metal in ordnance."

For the production of titanium in the metallic form, it has been decided by the Bureau of Mines that the Kroll process, in which titanium chloride is reduced by feeding the liquid slowly into molten magnesium in an iron chamber under helium at a temperature of 800° to 900°C., still offers the most possibilities. Some difficulties have been experienced in attempts to increase the size of the batch from 130 to 220 lb, as with the larger batch heat could not be dissipated fast enough to prevent the temperature rising until the magnesium began to boil. Then, as is described by F. S. Wartman, " the zone of reaction was shifted from the surface of the magnesium to the point where the magnesium vapour and titanium chloride both met at the end of the feed pipe. The heat of reaction, developed close to the lid, caused the metallic titanium to form the low-melting iron-titanum eutectic, which dropped down into the reaction mass."

The trouble has been largely overcome by feeding the titanium chloride into the reaction chamber through a rotating delivery pipe which sprays the liquid over a large area. This method has had the disadvantage that a solid impermeable layer of titanium forms across the top of the bath, but by breaking this by a bar inserted into the chamber at intervals, it has been found possible to operate with 220 lb batches. If larger batches are used, however, some radical changes in operating technique will probably become necessary. After reduction is finished, the mass is usually machined to turnings, which are leached with acid to dissolve unaltered magnesium and magnesium chloride leaving the titanium as a powder. The alternative process of volatalizing these in vacuum may receive greater attention in the future. It gives a product purer, as regards oxygen and hydrogen, but more likely to be contaminated with iron.

Titanium also appears to be available in the United States in the form of sodium-reduced metal which probably is less pure than the magnesium-reduced metal but which, on this account, may actually be preferable for some applications. For research purposes, pure titanium has been made by the Battelle Memorial Institute by thermal decomposition of titanium iodide in a vacuum on a heated filament to yield rods as much as $\frac{5}{8}$ in diameter and weighing from 700 and 750 gm. For this purpose, metal reaction tubes have been built. " Operation is so simple and satisfactory," writes Bruce W. Gonser, " that we consider glass tubes obsolete except for experimental work. A temperature of 165°C. is maintained easily by immersing the metal tube in a bath of circulating oil during deposition. Quality of product has been entirely satisfactory, probably partly because the larger volume of metal dilutes any impurities deposited at the start of a run."

Although the iodide process is still regarded by most workers as essentially a laboratory process it is of interest to note that Gonser concludes that " Power consumption has been as low as 40 kW-hr per pound of metal deposited, but is usually 60-75 kW-hr. Continued development of the iodide process may make it fully competitive with other methods for producing titanium commercially."