



# DATA SHEET No 18

## Titanium Powder Metallurgy

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Titanium powder metallurgy (P/M) offers the possibility of creating net shape or near net shape parts without the material loss and cost associated with having to machine intricate components from wrought billet. Powders can be produced by the *Blended Elemental Technique* or by *Pre-Alloying* and then consolidated by *Metal Injection Moulding*, *Hot Isostatically Pressing*, *Direct Powder Rolling* or *Laser Engineered Net Shaping*.

### Blended Elemental Technique (BE)

The traditional technique of titanium production is via the Kroll process, which involves chlorination of  $\text{TiO}_2$  ore in the presence of carbon and reacting the resulting  $\text{TiCl}_4$  with magnesium to produce titanium sponge. These processes take place at temperatures as high as  $1040^\circ\text{C}$ . The sponge particle range in size from 45 to 180  $\mu\text{m}$ , with particles  $\sim 150 \mu\text{m}$  termed 'sponge fines'. These fines are irregularly shaped and porous with a sponge like morphology. The fines are then blended with alloy additions; cold compacted into a green compact at up to 415 MPa then vacuum sintered at  $1260^\circ\text{C}$  to produce a 99.5% dense component. **Hot Isostatically Pressing (HIP)** can further increase the density of these parts and produce components more economically than cast or wrought parts, but the porosity present in the material degrades fatigue and fracture properties. The BE approach has been used to produce valves for the Toyota Altezza, golf club heads and softball bats. More recently, close to 100% dense Ti Grade 5 parts has been achieved using a hydrided powder along with 60:40 Al:V master alloy. The mechanical properties compare well with those exhibited by cast-and-wrought products. A cost estimate of less than \$3.00 for a 0.320 gm automotive connection link has been made.

*Tensile Properties of a Ti-Grade 5 compact produced from hydrogenated powder (after dehydrogenation)*

YS (MPa)	UTS (MPa)	EI (%)	RA (%)
840-860	940-990	7-10	11-27

### Pre-Alloyed Powder Production

Several techniques exist to produce pre-alloyed powder, such as Grade 5. In the **Hydride-Dehydride** process feedstock such as solid scrap, billet or machined turnings are processed to remove contaminants, hydrogenated to produce brittle material then ground under argon in a vibratory ball mill, typically at  $400^\circ\text{C}$  for 4 hours at a pressure of 1psi for Ti Grade 5. The resulting particles are angular and measure between 50 and 300  $\mu\text{m}$ . Cold compaction after dehydrogenation of the powder, followed by either vacuum hot pressing (in this case the dehydrogenation process can be bypassed as hydrogen is removed under vacuum) or HIP and a final vacuum anneal, produces powders with hydrogen below 125 ppm. The possible presence of contaminants makes these powders unsuitable for use in critical aircraft applications.

In the **Plasma Rotating Electrode Process (PREP)**, the feedstock, such as Ti Grade 5, is in the form of a rotating bar which is arced with gas plasma. The molten metal is centrifugally flung off the bar, cools down and is collected. The powders produced are spherical; between 100 and 300 $\mu\text{m}$  is size, with good packing and flow characteristics, making the powder ideal for high quality, near net shapes produced by HIP, such as aviation parts and porous coatings on hip prostheses.

In **Gas Atomisation (TGA Process)**, titanium is vacuum induction skull melted in a water cooled copper crucible, the metal tapped and the molten metal stream atomized with a stream of high pressure inert gas. The tiny droplets are spherical and measure between 50 and 350  $\mu\text{m}$ . The TGA process has been used to produce a wide variety of materials such as CP titanium, conventional alpha-beta and beta alloys.

## Powder Consolidation

Several metal consolidation techniques are used to produce the final product. **Metal Injection Moulding (MIM)** otherwise known as **Powder Injection Moulding** is a well-established and cost-effective method of fabricating small-to-moderate size metal components in large quantities. It is derived from the method plastic injection moulding, whereby mixing of a metal powder with a polymer binder forms the feedstock, which is then injected into a mould, after which the binder is removed via heat treatment under vacuum before final sintering. With titanium however, the binders used in MIM results in the introduction of carbon into the matrix due to insufficient binder removal prior to sintering and/or deleterious reactions between the decomposing binder, the debinding atmosphere, and the metal phase. This results in titanium parts with mechanical properties unsuited for critical aerospace applications, but suitable for parts where tensile and impact properties are less important. Recently, work has been carried out to reduce the binder to < 8% volume fraction, resulting in the complete removal of the binder from the moulded component during heat treatment. Work is still ongoing in this area.

Work is also progressing on the **Direct Powder Rolling (DPR)** process. BE powder is used to produce sheet and plate and composite multilayered sheet and plates. Sheets between 1.27 and 2.54mm and 50 to 99+% dense of single layer C.P. Titanium, Ti Grade 5, TiAl (Ti-48Al-2Cr-2Nb) and composite Ti/Grade 5/Ti and Grade 5/TiAl/Grade 5 have been produced by DPR and sintering.

**Laser Engineered Net Shaping (LENS®)** is an additive manufacturing technique for rapidly fabricating, enhancing and repairing metal components directly from CAD data. The processes use a high power solid state laser focused onto a metal substrate to create a ~1mm diameter melt pool. Metal powder is then injected into the melt pool to increase the material volume and build up the component layer by layer. Experimental gas thrusters (build time 8 hours) and automotive brackets have been manufactured in Ti-Grade 5. **Selective Laser Sintering (SLS®)** is similar, except that the laser selectively fuses powdered material by scanning on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed.

**Hot Isostatic Pressing** has already been mentioned as is a technique whereby high temperature and pressure are used to consolidate powders to close to their maximum theoretical densities.

## Emerging Technologies

Work is progressing on bypassing the conventional route of atomising wrought feedstock or sponge and the inherent cost associated with the traditional Kroll process. Several of these processes, such as the **FFC**, **MER Corporation**, **OS**, **Ginatta** and **BHP Billiton** processes rely on the electrolytic reduction of TiO<sub>2</sub> (a cheap and abundant material) to form Ti metal. So far, no material from these processes has been sold commercially on the open market, and cost models have yet to be published, but they offer the possibility of inexpensive titanium powder in the near future.

**For more information about the various suppliers and processors of titanium powder, please refer to TIG datasheet No. 19.**

## FOR FURTHER INFORMATION

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