SPECIAL FEATURE

Industrial application of titanium hydride powder

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Introduction

Titanium alloys possess unique combination of high strength, low density, and good corrosion resistance which makes them very attractive for many structural purposes. However, the cost of titanium produced by conventional ingot technology is high, compared to steels and aluminum, thus limits their use in automotive, military and other applications.

A conventional cold-compaction-and-sinter powder metallurgy (PM) approach is viable and promising route for cost effective fabrication of titanium alloys components, promoting overcoming this limitation [1]. The Blended Elemental Powder Metallurgy (BEPM) method uses the low cost starting blends of titanium powder and alloying powders (elemental or master alloy ones). Traditionally this method includes the consolidation of powder blends at room temperature by cost-effective conventional powder metallurgy processes such as die pressing, cold isostatic pressing (CIP), or by direct powder rolling, and subsequent sintering in vacuum for transformation of initial heterogeneous powder compacts into massive homogeneous alloys. A BEPM method is potentially the lowest cost manufacturing process to attain desirable characteristics of produced titanium alloys, especially if any secondary thermomechanical processing (hot deformation, HIP'ing, etc.) could be eliminated.

In order to achieve the desired levels of mechanical properties (such as strength, ductility, and fatigue strength), the BEPM sintered titanium alloys should not only have a homogeneous chemical composition and microstructure, admissible content of impurities, but also a relative density of greater than 98% of theoretical value. However, the relative densities of titanium alloys produced by a simplest BEPM press-and-sinter option normally do not exceed 95%. In order to increase the sintered density and balance of properties of titanium alloys without additional thermomechanical operations, the titanium hydride TiH_2 powder instead of conventional titanium powder can be successfully used, as starting material. An innovative and low cost manufacturing Non-Kroll process for production titanium hydride powder was developed [2]. It was demonstrated that the application of titanium hydride powder significantly improves the synthesis of PM Ti–6Al–4V and some other alloys. Better homogeneity and relative density of 98–99% was attained with a simplest press-and-sinter approach and without any additional processing operations. Attained mechanical properties meet specifications for corresponding cast/wrought titanium alloys [3,4]. This technology (ADMATAL^{TM}) was invented and patented by ADMA Products, Inc. (USA) and Institute for Metal Physics (Ukraine) [5]. A great contribution to the development of theoretical and practical aspects of using titanium hydride powder, were done by V.S. Moxson, O.M. Ivasishin and their teams [6–8].

Production of low cost titanium hydride powder

While the conventional PM processing is well developed and mature industry, the commercial success of titanium hydride PM depends on the availability of low-cost but high-quality titanium hydride powder. Conventionally, titanium hydride is being produced by hydrogenation of low-grade titanium sponge, turnings, and other titanium materials. Production of hydrogenated titanium in the foresaid methods is based on hydrogenation of already produced titanium materials; therefore, its cost cannot be lower than those of the primary titanium products. However, in order to meet the requirements of low-cost raw material, the titanium hydride powder should be, at least, equal or less expensive than the primary titanium products.

A revolutionary new approach for manufacturing the hydrogenated titanium powder was developed by ADMA Products, Inc. in cooperation with PNNL and Ukrainian partners (Institute of Titanium and IMP) [9,10]. Its key feature is integration of titanium production and its hydrogenation in one continuous cycle, including reduction of $TiCl_4$, vacuum distillation, and

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0026-0657/© 2016 Published by Elsevier Ltd. http://dx.doi.org/10.1016/j.mprp.2016.02.051

$$TiCl_4 + H_2 + Mg \rightarrow TiH_2 + MgCl_2$$
$$TiCl_4\,(gas) + H_2\,(gas) \rightarrow TiCl_3\,(solid) + HCl\,(gas)$$
$$TiCl_3\,(solid) + Mg\,(liquid) \rightarrow Ti + MgCl_2$$
$$HCl\,(gas) + Mg\,(gas) \rightarrow MgCl_2\,(liquid) + H_2\,(gas)$$
$$Ti + H_2\,(gas) \rightarrow TiH_2$$

FIGURE 1

Chemical reaction with hydrogen during reduction of titanium.

hydrogenation of the sponge block in the same vessel upon cooling from the distillation temperature. It makes this process different from normal operations of removing the titanium sponge block from the vessel at the end of the reduction/distillation cycle, crushing of the block, and, finally, performing hydrogenation of crushed sponge in another vessel.

Further developments of titanium hydride powder manufacturing process were accomplished by ADMA Products, Inc. [11,12]. Magnesium–hydrogen reduction process was proposed as the most cost-effective approach to produce the low-cost, high-quality titanium hydride powder (Fig. 1). In this process, magnesium is partially replaced with hydrogen as a reducing agent.

The use of hydrogen during the reduction stage significantly shortens successive vacuum distillation stage and allows lower distillation temperature. Distillation is done in such a way that hydrogenation/dehydrogenation steps follow each other several times, resulting in a highly developed porosity and cracking due to an 18% difference in titanium and titanium hydride densities. The composition of titanium hydride powder (Fig. 2) averaged from 25 lots produced by ADMA process is presented in Table 1.

Wide possibility of manufacturing the TiH_2 powder with different particle size distribution

The sponge comminution process becomes simpler, since the brittle hydrogenated titanium can be mechanically ground to the desired particle size inside the retort and then extracted and compacted in an inert environment for subsequent compaction steps. Furthermore, if necessary, the TiH_2 powder after grinding can be dehydrogenation in the same retort and used like any other titanium metal powder.

TABLE 1

Chemistry of TiH_2 powder produced by ADMA technology.

Material	Fe	N	C	O	H	Ti
ADMA TiH_2 powder	0.03–0.16	0.03	0.01	0.063	3.8–3.85	bal

High fragility of titanium hydride sponge allows producing fine TiH_2 powder for a very short period of time (Fig. 3). New technology of grinding of as-produced TiH_2 sponge inside the retort after hydrogenation process not only provides high energy cost saving but also allows to produce powder with much lower oxygen content (0.0457%) compare to traditional titanium crushing/grinding processes (0.115%) (Fig. 4).

A pilot-scale unit (Fig. 5) with an annual capacity of 250,000 lb of TiH_2 powder was installed at ADMA facilities. At least 50% energy savings and 20% cost reduction relative to existing commercial Kroll's process are expected at full commercialization of the ADMA process.

Manufacturing of titanium alloy components from ADMA hydrogenated titanium powder

Early works have demonstrated that Ti–6Al–4V alloys produced from hydrogenated titanium powder resulted in low impurity content material that meet ASTM and AMS standards without extraordinary measures associated with multiple vacuum melts in conventional processing [1,7]. The advantages of using TiH_2 powder are: low content of oxygen and chlorine in titanium finished products, achieving the high density in low-cost cold-compaction-and-sinter PM sintered parts.

Purification of material during sintering

Hydrogen is an interstitial impurity and its increased content in titanium, like increased oxygen, leads to degradation of ductile properties and also to loss in strength. However, contrary to oxygen's affinity for titanium, hydrogen possesses the useful capability not only to saturate titanium to necessary concentrations, but then to be completely removed from material under determined pressure-temperature conditions. This fact allows the successful use of TiH_2 powder in BEPM processing with dehydrogenation of base powder during vacuum heating and eventual

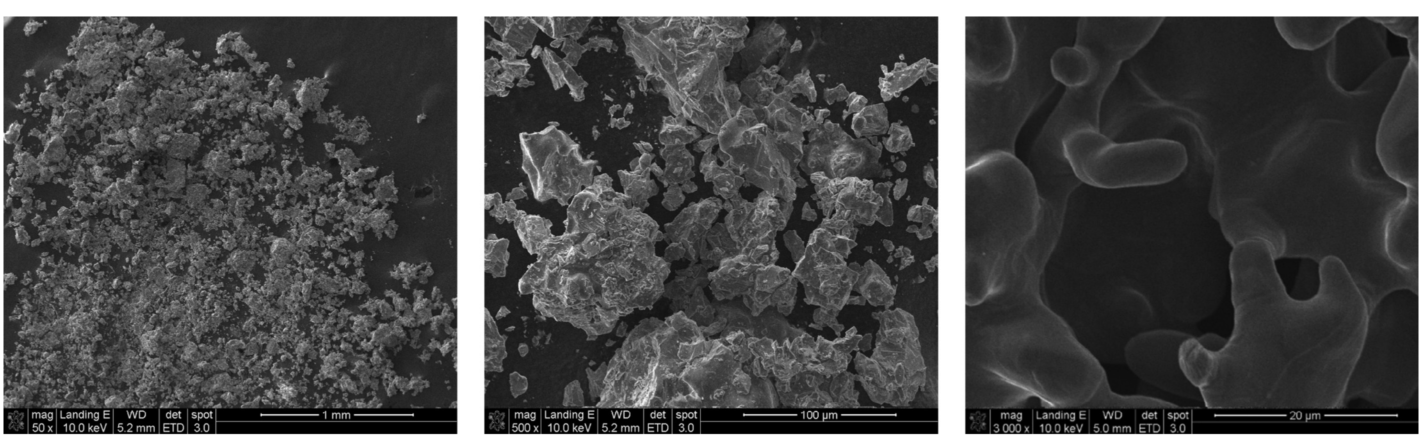

FIGURE 2

Representative micrograph of TiH_2 sponge and TiH_2 powder.

Please cite this article in press as: V. Duz, et al., Met. Powder Rep. (2016), http://dx.doi.org/10.1016/j.mprp.2016.02.051