POWDER METALLURGY TITANIUM TRIMS COST OF EXTRUSION BILLETS FOR MAKING APPLIQUÉ ARMOR ATTACHMENTS

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ABSTRACT

Defense vehicle manufacturers use self-tapping threaded mechanical fasteners to mount various components onto the vehicle structure quickly. A new program focuses on a high volume-potential powder metallurgy manufacturing process to produce titanium alloy extrusion billets to make rod feedstock for threaded attachment inserts. Powder characterization, compaction and vacuum sintering processes are used to make cylinder preforms to manufacture bar stock from which inserts are fabricated. Processing factors and comparative performance testing of inserts made from conventional melt-formed industrial titanium stock vs. powder metallurgy titanium are discussed.

1. INTRODUCTION

The US military values titanium as an armament material, especially in recent years with the increasingly lethal threats. The unique combination of high strength and low density, along with excellent fatigue and mechanical properties and outstanding corrosion resistance make titanium a highly advantageous material for many structural applications. The use of titanium in military vehicles promises to save weight and reduce the fuel logistics tail for these weapon systems. Conventional melt-cast-forge or rolled titanium alloy products have higher costs and longer delivery lead times when compared to steel, aluminum or magnesium alloys, and the demand for aircraft grade titanium alloys for aerospace applications creates a cyclic titanium market. Predictions show that if more volume were produced, the price for non-aerospace-grade titanium alloys could drop.

Solid-state Powder Metallurgy (PM) is a mature industry for other metals like stainless steels, copper, brass and aluminum alloys. U.S. market data show that the PM industry comprised >$5 billion total vs. $5 million domestically for titanium in 2006 (Sheppard, 2007). The most cost effective PM processes employ low cost blended elemental (BE) powders of commercially pure (CP) titanium mixed with Master Alloys (e.g., 60:40Al:V) to formulate alloys such as Ti-6Al-4V. The powder blends are molded into the pre-forms of the required shapes. Then, during the sintering, inter-diffusion between the particles takes place, causing a densification and homogenization of chemistries and ultimately producing full density materials. PM titanium parts generally comprise small volumes such as washers, bushings bearings and seals. Competitively priced CP Ti powders are now available for ~$20/lb, and the market is expanding.

2. THREADED INSERTS

Appliqué armor is the primary mode for survivability upgrades for all legacy combat and tactical systems (e.g. USMC LAV, Army HMMWVs, Bradleys, Abrams, trucks, etc.). The primary mode for attaching high performance lightweight appliqué armor is through mechanical fasteners to provide a durable threaded hole in dissimilar materials that can support the mating bolt or screw. Each vehicle uses thousands of inserts to attach appliqué armor and many other components. The GDLS proprietary insert, Fredsert®, is a self-tapping threaded insert for use in mounting a component onto a structural member on which the insert is mounted (Wheeler, 2003). Fredserts are used on the EFV, Stryker, Navy LPD turrets, and FCS platforms. They are unique from other solid inserts in that they have no fixed mechanical locking, which means they are easily removed and replaced for maintenance repairs. The inserts come in a variety of sizes, as shown in Figure 1, and offer self-tapping threads designed to store chips at the base, and a locking flange. The current cost of these inserts is high because they use the same aerospace-grade titanium used to manufacture aircraft components.

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Figure 1. FREDSERT inserts come in a range of sizes to accommodate a range of metal mounting applications.

3. PM Ti-6Al-4V PROCESSING

3.1 Ti-6Al-4V Powder Metallurgy Preform Billets

Hydrogenated titanium powder is a raw material used to manufacture various components using the low cost blended elemental PM approach (Drozdenko et al., 2003). The hydrogen in titanium powder assists with the densification of the preform/compact and cost reduction. Early trials have demonstrated that Ti-6Al-4V alloys produced with hydrogenated titanium powder result in low interstitial grade material meeting ASTM standards without extraordinary measures associated with multiple vacuum melts in conventional processing (Adams et al., 2008; Savvakin et al., 2005).

The cold-isostatic press room temperature process (CIP) is a relatively inexpensive process combining hydrostatic compression of titanium powders in a flexible mold to make dense near-net shape parts or preforms for subsequent shaping processes such as forging or hot rolling. No binders are required to hold the powder particles together. The workpiece is removed from the mold and then vacuum sintered to >99% theoretical density. Figure 2 shows a number of dense sintered cylindrical preforms ready to be removed from the vacuum furnace. The inset shows the microstructure of the as-sintered Ti-6Al-4V. Because mechanical working of the alloy increases the physical properties, expectations are that the rod stock produced from PM alloy will exceed the standard requirements.

Figure 2. PM Ti-6Al-4V extrusion billets shown in the vacuum sintering furnace after densification.

3.2 Rod Stock Forming

There are three standard industrial processes used to produce the bar stock: roll forming, rotary forge (also known as flow forming), and extrusion, listed in the order of increasing cost and properties. All three processing paths are being used to determine the difference in properties. Initially, starting billets of sufficient size to produce three to five meters of 0.875 cylindrical rod stock that is the starting material for insert fabrication will be provided to processers.

An extrusion workability study that compared powder-based and ingot-based billets showed that the PM billet is less demanding on press forces than an ingot-based billet (Yu, 2008). The estimate is that PM extrusion processing uses ~ 20% lower press pressures as compared to an identically processed ingot-based product form.

In order to have a direct comparison between starting preform materials, Fredserts will be fabricated by Miller Precision Manufacturing, Inc., Ottoville, OH, the vendor that currently manufactures Fredserts for GDLS. After the rod forming methods have been evaluated for the most common insert size, rod stock with diameters ranging from 1.59 to 3.81 cm will be produced in order to evaluate properties for a variety of additional Fredsert insert sizes.

3. INSERT EVALUATIONS

3.1 Evaluation plans

Following fabrication, the prototype inserts will be characterized to insure that they are suitable for the intended application. Characterization will be done for inserts made from both conventional melt-formed industrial titanium stock vs. powder metallurgy titanium. This will include chemical composition, microstructural analysis, mechanical property testing (tensile testing, hardness, limited S-N fatigue testing and wear characteristics) and corrosion behavior using standard

ASTM techniques. The evaluation criteria are shown in Table 1.

Table 1. Evaluation criteria to compare inserts fabricated using PM vs. Conventional Ti-6Al-4V Rod Stock

EVALUATION CRITERIA
A. PM PREFORM BILLET
Metallurgical Properties Microstructure Analysis Chemical Composition Analysis
B. ROD STOCK
Metallurgical Properties Microstructure Chemical Composition Surface Contamination Tensile Strength Shear Strength Tension Fatigue Tolerances
C. FREDSERT COMPONENTS
Tensile Strength Shear Strength Install & Breakaway Cycles Salt Fog Corrosion Over-torque strain

A tradeoff analysis to evaluate performance properties versus cost and processing factors is part of the program. Table 2 shows initial calculations of savings that PM metallurgy used to produce Ti-6Al-4V rod mill stock could yield.

Table 2. Calculation of Estimated Savings Based on the EFV and FCS Weapons Systems

Cost Basis			
Current cost of Ti-6Al-4V preform billet = $77/kg Projected Ti-6Al-4V PM billet = 39.60/kg Difference = $ 37.4/kg			
Size Basis			
Average insert uses 3.175 cm dia. x 3.8 cm long rod stock Volume average insert = 0.133 kg of Ti-6Al-4V			
Savings based on projected vehicle production			
Quantity per Vehicle	# Vehicles	Production# Fredserts	Total Estimated Savings, $
EFV: 3000	500	1500000	7,506,563
FCS: 1000	4000	4000000	20,017,500

3.2 Results to date

After a much-delayed start, PM Ti6Al-4V performs (see Figure 3) have been produced and are ready to be sent to be rotary-forged into meter-lenth rod stock.

Figure 3. A 14 cm dia. x 35 cm long CIP/sintered/ground preform input billet prepared for rotary forge conversion into 2.22 cm dia x 3.66 - 4.57 m length Ti-6Al-4V rod.

Table 3 shows initial data for the as-sintered properties of PM Ti-6Al-4V compared with the standard requirements set forth for the mill product rod stock.

Table 3. As-sintered physical properties CIP/sintered PM Ti-6Al-4V as compared with the insert AMS Standard requirement.

PROPERTIES	AMS 4928 Standard: Annealed Ti-6Al-4V	As-sintered PM Ti-6Al-4V
Density, gcm^{-3}	4.43	4.40
Ultimate Tensile Strength, MPa	950	999
Tensile Strength, Yield, MPa	880	924
Elongation at Break, %	14	15
Reduction of Area, %	36	31
Modulus of Elasticity, GPa	113.8	112.4
Fatigue Strength, 10^6 cycles, MPa	510	600*

*(Ivasishin et al., 2004)

CONCLUSIONS

Production of powder metallurgy titanium components may lead to a substantial reduction in the cost of parts compared to those produced by conventional cast and wrought (ingot metallurgy) processes and therefore, has the potential to increase the use of titanium. Titanium alloys have many attractive commercial uses. Due to their excellent strength-to-density ratio, stiffness, high temperature and corrosion resistance, titanium alloys can be adapted to a great variety of applications such as those required by the aeropace, automotive, sporting goods and other industries. Titanium alloys have the greatest potential volume usage in vehicle applications, but expensive processing costs limit their current serviceability in this and other highly cost conscience applications in both the public and private sectors.

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