N. Low-Cost Powder Metallurgy Technology for Particle-Reinforced Titanium Automotive Components: Manufacturing Process Feasibility Study (AMD 310[i])

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Objective

- Demonstrate production-intent process scheme for fully-densified titanium-alloy, powder-metallurgy (PM) composite samples.
- Benchmark process capability using commercial-grade titanium powder feedstock and follow with one of the proposed low-cost titanium powder materials. Blend additives to achieve final titanium-alloy material with reinforcement.
- Perform microstructure characterization and interfacial studies.
- Confirm test specimens are crack-free by nondestructive evaluation method (Lawrence Livermore National Laboratory).
- Generate static mechanical properties and perform failure analysis.
- Perform a technical cost modeling study on the novel ADMA Products, Inc., process and establish sensitivity of each processing step for cost-effectiveness.

Approach

- Use titanium metal feedstock to produce blanks in simple shapes via the ADMA manufacturing process that will then be machined into coupons for mechanical property determination.
- Conduct microstructural and interfacial studies together with mechanical property testing.
- Perform a technical cost model on the ADMA manufacturing process.

Accomplishments

- Produced powder blends of Ti-6Al-4V material from Sodium Reduced Ti sponge fines with and without reinforcement (benchmark material).
- Received powder blend of Ti-6Al-4V material from International Titanium Powder (ITP) without reinforcement (low-cost alterative).
- Die-pressed powders in 0.500-in.-diameter carbide tooling to 0.500-in. thickness for metallographic examination.
- Compacted and processed powder blends into 3 inch x 5 inch blanks for tensile samples.
- Sintered in vacuum furnace, optimized heat treatment.
- Machined blanks into tensile samples.
- Completed metallographic examinations and tensile tests.
- Completed fracture analysis on composite material.
- Completed cost model on ADMA manufacturing process.
- Assessed cost model and mechanical properties against decision-gate criteria.
- Completed USAMP final report.

Introduction

The goal of this concept-feasibility study is to develop a low-cost PM manufacturing process to obtain fully-dense parts based on current commercial-grade materials and a novel processing technology. The study will use particle-reinforced titanium metal feedstock in conjunction with PM press-and-sinter technology to manufacture simple parts for testing. A technical cost model will be performed to document the cost of the manufacturing process. The decision gate criteria are (1) a cost-competitive manufacturing process and (2) acceptable microstructure and mechanical properties that have been identified for connecting rods targeted for high-performance reciprocating engine applications.

Low reciprocating-mass components are being sought by the domestic automakers in the FreedomCAR partnership for the next-generation of high-efficiency engines. The USAMP research objective for Ti has been set at 50% weight reduction and at < 3 times of the cost of powder forged iron-base connecting rods in production. Other benefits of titanium connecting rods due to high strength/weight ratio are, enhancing the horsepower without changing the engine architecture, reducing NVH to potentially eliminate the balance shaft system, etc.

ADMA Products, Inc. has developed a full-density (99% dense) powder metallurgy press-and-sinter process for titanium and its alloys. The process with near–net shape capability offers considerable cost savings over current isostatic pressing and/or hot forging/extrusion type processes. The study plans to extend the technology to titanium metal matrix composite for connecting rod application.

The approach is to use Ti metal feedstock to produce blanks in simple shapes via the ADMA process that will then be machined into coupons for mechanical property determination. Microstructure and interfacial studies together with mechanical property testing will be carried out by the team including outside sources jointly selected.

Target mechanical properties to be reached are ultimate tensile strength and yield strength of 750 MPa (107 KSI) and 670 MPa (96KSI), respectively with elongation exceeding 6%. Furthermore, microstructure has to be uniform and free of segregation. Had the study demonstrated the ability to reach the set property target, the costs of materials / manufacturing processes developed have to be established to ensure that it is cost competitive. Development of actual component would be the next step for consideration.

Conclusions

The study demonstrated the ability to reach the decision gate target. Room-temperature tensile properties for as-sintered Ti-6Al-4V alloys have met the target values set for the study. It would produce Ti alloys reaching the fully-densified state in simple geometry. The whole operation, using blended elemental powders and simple press-and-sinter P/M operation, was carried out in a cost-effective manner.

The process also appeared to be capable of producing nearly full-density Ti metal-matrix composites (MMCs) in a cost effective manner. The Ti-6Al-4V metal matrix was successfully reinforced with carbide particles, via the press-and-sinter P/M technology in conjunction with the blended elemental powder approach. Reinforcement improved modulus of elasticity up to 20%.

The project covered 17 Ti-base alloy compositions. Some of them were processed with the conventional press-and-sinter P/M technology, and others were hot pressed, forged and with limited heat treat to optimize microstructure and properties.

The original intent was to evaluate the concept of producing fully densified parts via powder metallurgy approach starting with a hydrogenated titanium powder. However, neither the hydrogenated powder nor hydrogenation process was available at the beginning.
Only high-purity titanium powders were used for this study - reduced by sodium, magnesium, calcium, to name a few. The goal of full density consolidation remained the same. Titanium powder from ITP Armstrong process became available toward the end of this study.

Future

This project has ended and report flied with the USCAR.

Recommend future work includes:

1. Additional refinement on sintering cycle for Ti-MMC to improve properties in the already full density condition. As stated, fully densified state is the first (major) step and a pre-requisite for any further property improvement from the consolidation point of view (via P/M approach). Certain properties like fatigue, fracture toughness, corrosion resistance, etc can be improved further while remaining in the full density state.
2. Cost analysis based on the developed materials and processes should then be performed to ensure its cost effectiveness.
3. Hydrogenated powder approach should be explored in search for more cost effective manufacturing process.

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[i] Denotes project 310 of the Automotive Metals Division (AMD) of the United States Automotive Materials Partnership (USAMP), one of the formal consortia of the United States Council for Automotive Research (USCAR), set up by the “Big Three” traditionally USA-based automakers to conduct joint pre-competitive research and development.