E. Low-Cost Titanium Evaluation

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Objectives

- Investigate alternate powder and melt processing methods for low-cost titanium materials.
- Evaluate processing methods to produce powder metallurgy (PM) titanium products with International Titanium Powder, Inc. (ITP) powder.
- Evaluate the suitability of emerging titanium technologies for the production of low-cost titanium products for automotive applications.

Approach

- Perform characterization and analysis of the sintering behavior of the ITP powder. Provide feedback of results to ITP for use in process design.
- Perform thin-section slab castings and roll to sheet to simulate and evaluate the use of continuous casting methods to produce sheet materials.
- Survey the emerging technologies for the low-cost production of titanium powders and evaluate for use in automotive applications.

Accomplishments

- Developed press and sinter cycles that produced greater than 97% dense plates of cold-pressed (CP) titanium from the ITP powder.
- Hot-rolled plates pressed and sintered from CP titanium ITP powder with a 2.5:1 reduction exhibited limited ductility in bend tests. Fracture surface evaluation showed that although densities were high, large amounts of the powder had not sintered.
- Designed and fabricated in cooperation with Albany Research Center (ARC) and CANMET, graphite molds for plate casting trials to determine the effect of solidification rate on the reduction of area required to produce wrought properties.

Future Direction

- Perform dilatometry, thermogravimetric (TGA), microstructural analysis, and XRD analysis to develop a sintering cycle that can eliminate sodium impurities and improve sinterability at lower pressing pressures.
- Continue the development of sintering cycles for the ITP powder with an emphasis on understanding the sintering mechanisms of the powder to increase ductility.
- Continue evaluations to determine the cause of the low ductility of compacted material produced with ITP powder.
- Evaluate alternate low-cost titanium feedstocks for powder or melt processing to wrought products.
- Evaluate mechanical properties of step-plate castings produced at ARC.

Introduction

An automobile design trend that has received much attention has been the reduction of vehicle mass. Reducing mass can improve both performance and fuel economy. While design changes can play a large role in reducing mass, large reductions ultimately will require the substitution of higher specific strength/stiffness materials in place of carbon steel. Primary contenders in this race are high-strength steels, aluminum, and fiber-reinforced polymer composites. One material not on this short list, but one that could provide further reductions, is titanium. Although titanium is light and strong, its role in the automobile has been almost nonexistent because of its exorbitant price. This high price is a direct result of the current production route, the Kroll process, which is time-consuming; energy-, capital-, and labor-intensive; and batch-based.

However, new technologies are emerging that may change the characteristics of the titanium market. In particular, these technologies may reduce the titanium price sufficiently to allow it to compete in high-volume markets, possibly even automotive. This project examines the powder metallurgy (PM) behavior of titanium powder produced by a new process being developed by ITP.

Approach

The production of low-cost titanium for automotive applications will require cost reductions in both raw materials and secondary processing operations. The approach to this project will be to evaluate the suitability of emerging titanium beneficial technologies and secondary operations, such as rolling to sheet by continuous casting and solid state methods. The ITP powder process produces an alloy powder with morphology very similar to the emerging technologies, FFC Cambridge and MER anodic reduction. Because ITP can produce powders in sufficient quantity for evaluation, the ITP process will be used as an evaluation of new secondary processing operations such as continuous rolling and solid-state sheet production.

Results and Discussion

Previous reports[1–3] of ITP powder processing indicated that sodium compounds were assumed to be limiting the density and tensile ductility of the sintered pressing. Thermo-gravimetric (TGA) results of ITP powders indicated that sodium compounds were present and began to decompose at temperatures near 500°C. Dilatometry of a pressed powder compact, given in Figure 1, showed that sintering of the compact initiated at 475 to 500°C.

Additionally, it was shown that vacuum distillation of NaCl from titanium sponge was a very slow process (which explains why titanium sponge

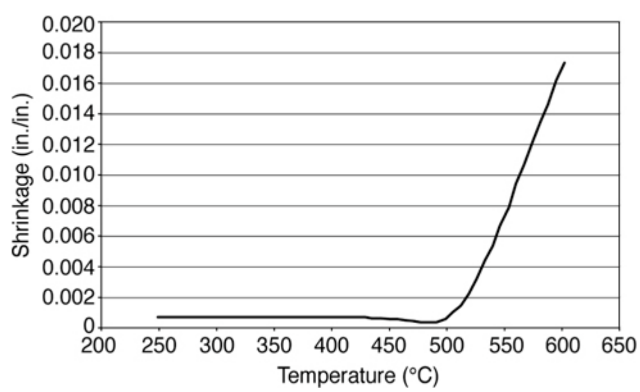

Figure 1. Sintering shrinkage of an ITP CP titanium powder pressed at 60,000 psi using a heating rate of 5°C/min.

produced by the sodium-reduced Hunter process was washed, and the magnesium-reduced Kroll processed sponge was vacuum distilled.)[4] The result of the combination of factors can result in sintering prior to complete removal of deleterious impurities such as sodium. Therefore, a sintering cycle was used at 1100°C that included an 8-h hold at 500°C to assist in distillation of any sodium compounds prior to excessive sintering. The result was a 97+% dense plate that, after rolling with 2.5:1 reduction, exhibited ductility in a bend test.

Analyses of the fracture surface and partially sintered powder, given by Figures 2(*a*) and 2(*b*), respectively, indicate that even with a high bulk density, a large quantity of the powder has not sintered and bonded.

This was not an expected result given the very fine size of the powder and the reactivity of titanium. When sintering of the ITP powder was performed, a relatively constant 11 to 15% density increase was observed; whereas atomized Ti-64 powder processed in parallel exhibited as much as a 30 to 40% density increase as illustrated here in Figure 3. At this point the sintering mechanism of the ITP powder particle must be studied to determine what process parameter must be modified to enhance particle growth and bonding. This can include sintering temperature, sintering atmosphere, and heating rate during sintering.

Increased compaction pressure, 75,000 psi, and slow heat times, 5°C/min, were used to produce powder compacts with densities in excess of 95%. The compacts processed using the exhibited limited ductility, 3%, did not show the regions of unsintered material observed in previous trials. Figure 4 has

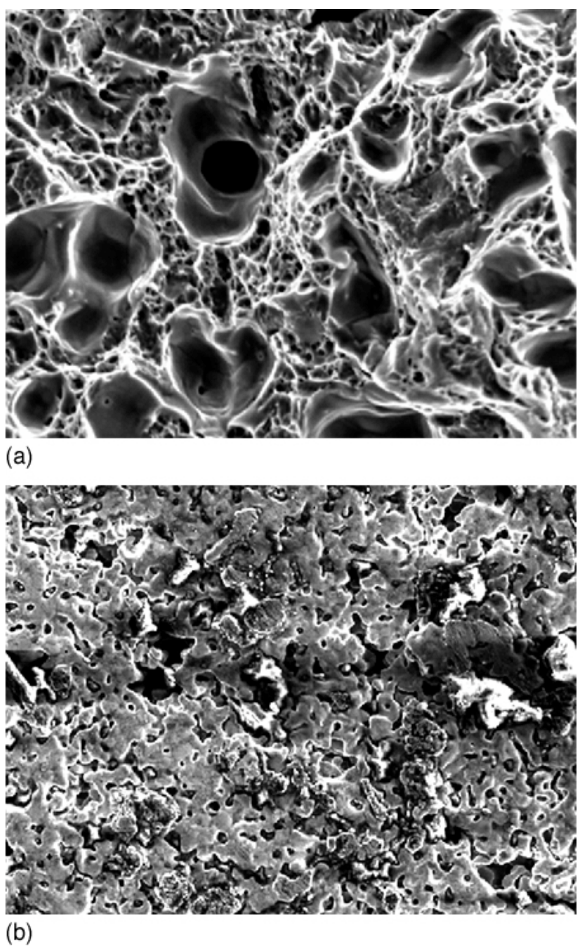

Figure 2. Fracture surface (*a*) and sintered structure (*b*) of sintered CP titanium powder indicate incomplete sintering even though bulk density was in excess of 97%.

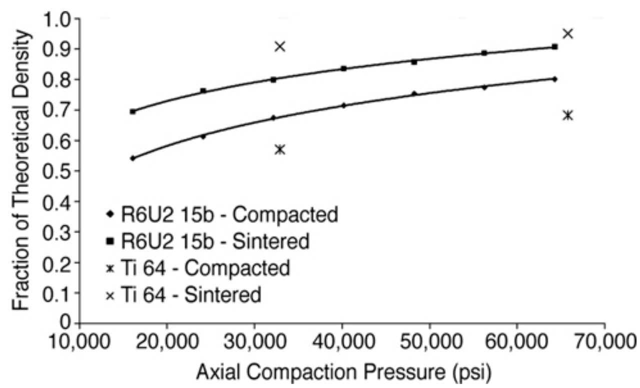

Figure 3. The fraction of theoretical density as a function of axial compaction pressure for ITP CP titanium and atomized Ti 6Al 4Vpowders.

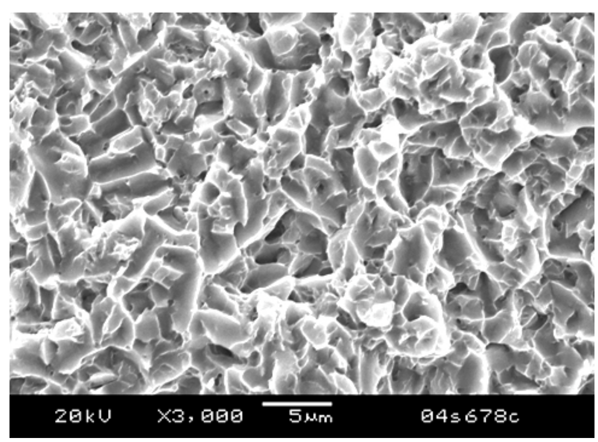

Figure 4. Fracture surface of sintered compacts of ITP powder processed at Pacific Northwest National Laboratory, indicating that relatively complete sintering of the compact has been achieved.

been included to illustrate the fracture surface observed in highly sintered ITP powder compacts, illustrating that relatively complete sintering has been achieved.

Progress was made in the development of the step-cast plates at Albany Research Center (ARC). Complete die fill was achieved through a series of design iterations on the mold. All cast plates have been delivered to CANMET for evaluation. Figure 5 has been included to illustrate the typical step cast plate developed by ARC and delivered to CANMET.

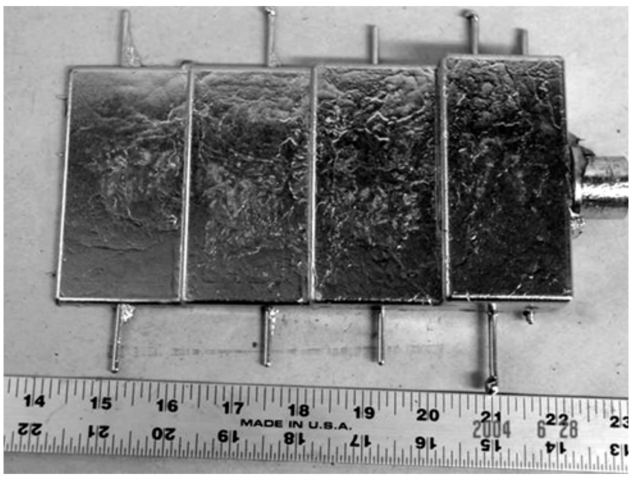

Figure 5. Step plate castings developed for evaluation at CANMET.

Conclusions

- Sintering conditions for the ITP can be developed to produce ductility. Optimization of the sintering cycle must be performed to maximize ductility.
- The sintering mechanism of the ITP powder is different than atomized powder, and conditions must be developed to maximize the volume of powder sintered.

References

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