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Investigation into the microstructure and tensile properties of unalloyed titanium and Ti-6Al-4V alloy produced by powder metallurgy, casting and layered manufacturing

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ABSTRACT

Solid titanium (Ti) and Ti-6Al-4V (wt.%) materials were fabricated from powders using spark plasma sintering (SPS), cold isostatic press (CIP) and sinter, layered (rapid) manufacturing, centrifugal and vacuum casing. ASTM Grade 4 Ti, Al and V, 60Al-40V (wt.%) and the pre-alloyed Ti-6Al-4V powders were used as starting materials. The solid Ti and Ti-6Al-4V materials produced by the SPS were compared to the CIP and sinter method on the basis of density, microstructure and chemistry. The materials produced by the CIP and sinter method were also compared to those produced by vacuum casting method on the basis of microstructure, oxygen pick-up, chemistry and room temperature tensile properties. Centrifugal casting was compared to the vacuum casting technique on the basis of microstructural homogeneity. Rapid manufacturing was compared to SPS and CIP and sinter on the basis of microstructural homogeneity, density and tensile properties. The tensile properties of all materials were also compared to their commercial counterparts to investigate the effect of interstitial oxygen. The technology resulting in materials with superior properties was finally identified as most promising for commercial production of Ti-based materials.

On the basis of densification, the SPS method appears superior compared to the CIP and sinter and rapid manufacturing method due to the benefit of pressure aided sintering, while the rapid manufacturing method is superior to the CIP and sinter method due to the use of a high power laser resulting in high densification rates. In cases where microstructural homogeneity is the key requirement, the CIP and sinter and rapid manufacturing methods appear superior compared to the SPS method due to longer isothermal holding time and higher sintering temperature and the use of pre-alloyed Ti-6Al-4V powder, respectively. On the basis of oxygen pick-up and additional contamination, the vacuum casting route is inferior due to the tendency of melt-crucible interaction, resulting in the dissociation of ZrO_2 and subsequent pick-up of O and Zr. Based on the homogeneity of the microstructure, centrifugal casting is better than vacuum casting. The ductility of vacuum cast Ti was better than that of CIP and sintered Ti, possibly due to limited diffusion of oxygen from the crucible compared to oxygen absorbed from the controlled atmosphere during CIP and sinter. The vacuum casting of the Ti-6Al-4V alloy resulted in dissolution of oxygen and Zr due to melt-crucible interaction. Hence the ductility was worse compared to the alloy produced by CIP and sinter. The rapidly manufactured Ti-6Al-4V specimens exhibited superior ductility and

strength compared to all alloys produced by other methods due to the use of high purity starting powder. The tensile properties of these specimens were also comparable to standard requirements. The similarity of the tensile properties of wrought Ti-6Al-4V alloy reported in the literature was an indication of limited oxygen pick-up during rapid manufacturing. Therefore based on low oxygen pick-up, microstructural homogeneity, high density and superior tensile properties, the rapid manufacturing route appears to be the most promising approach for commercial processing of titanium based materials.