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The Effects of Electron Beam Melting on the Microstructure and Mechanical Properties of Ti-6Al-4V and Gamma-TiAl

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Titanium alloys have been used extensively in the aerospace and biomedical industries due to their high strength to weight ratios, elevated temperature mechanical properties, excellent biocompatibility, and good corrosion resistance [1-4]. Alloys, such as Ti-6Al-4V (Ti-6-4) can be used for replacement hip joints, knee joints, and bone plates because of the aforementioned properties. Titanium-aluminum intermetallic alloys such as γ-TiAl are attractive for high temperature turbine engine components because of their good thermal stability and low density [5]. Recently, both of these alloys have been manufactured with additive manufacturing (AM) because traditional methods such as casting and forging present problems and limitations [5]. AM provides more design flexibility for titanium alloys, a great benefit when considering the complexity of certain parts made for biomedical implants or jet engines. Electron beam melting (EBM) is a powder processing AM technique that produces fully net shaped parts from a bed of powder, and it is the main focus of this study.

In this research, the microstructure and mechanical properties of both Ti-6-4 and γ-TiAl were studied before and after the EBM process. X-Ray diffraction (XRD), nanoindentation, and micropillar compression were performed to gain an understanding of the effects of the EBM manufacturing process. Microstructural evaluation was performed with the use of a scanning electron microscope (SEM). Figure 1 (a)(b) shows the microstructure of Ti-6-4 and γ-TiAl, respectively. Both alloys form a fine lamellar microstructure of alternating phases; these needle like Widmanstätten structures serve to strengthen the alloys by reducing crack propagation through the material.

Micropillars prepared by focused ion beam (FIB) milling were compressed by a nanoindenter in order to gather the yield strength and Young's modulus. Stress/strain curves for micropillars are shown in Figure 2(a) and (b) for Ti-64 and γ-TiAl, respectively. Tabulated values for the experimentally calculated compressive yield strengths, hardnesses, and Young's Moduli are shown in Table 1. From Table 1, it is clear that the EBM manufacturing process has a positive effect on the mechanical properties of Ti-6-4 and γ-TiAl. Compared to a cast sample of Ti-6-4 that underwent identical testing, the EBM sample displayed yield strengths that were 39% higher on average. This is due to the microstructure that is formed upon cooling. Specifically for Ti-6-4, the β phase that forms enhances the mechanical properties, as it has a higher strength than the α phase and also acts as a strengthening phase [6]. Referring to Figure 1, very fine spacing of the lighter β phase can be observed. The mechanical properties found for γ-TiAl agree well with calculated and experimental values from the literature with a Young's modulus of 179 ± 5 GPa.

From this research it can be concluded that the manufacturing process plays a significant role in the final mechanical behavior of a material. In the case of Ti alloys, there seems to be a strengthening effect due to the faster cooling rate and favorable microstructure that forms as a result. Future work to be performed will involve a TEM analysis of the deformation mechanisms of both materials as well as an analysis of the base powder from which EBM samples are produced.

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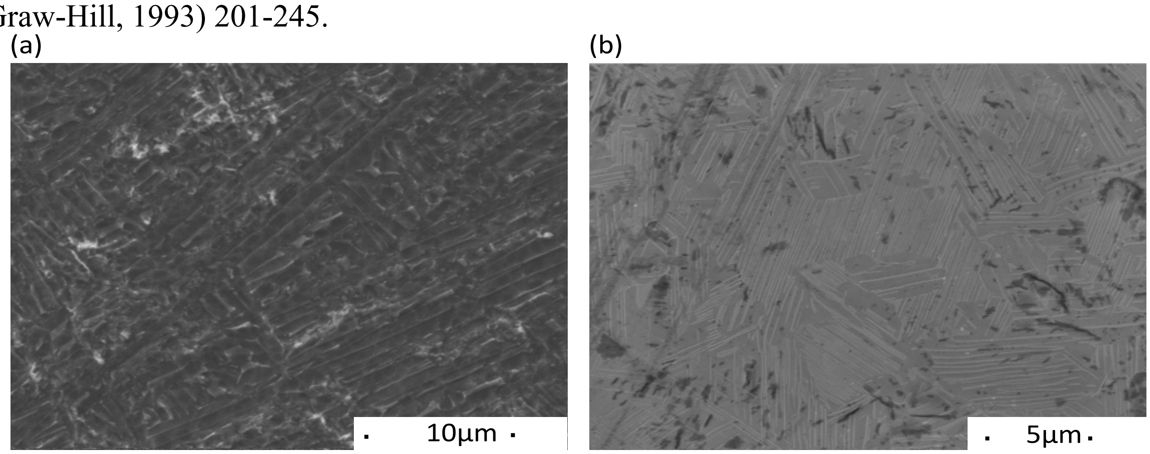

Figure 1: SEM images of microstructures for (a) Ti-6-4 showing the V rich β phase (lighter) and Al rich α phase (darker) and (b) γ-TiAl showing the α_2-Ti_3Al phase (lighter) and γ-TiAl phase (darker)

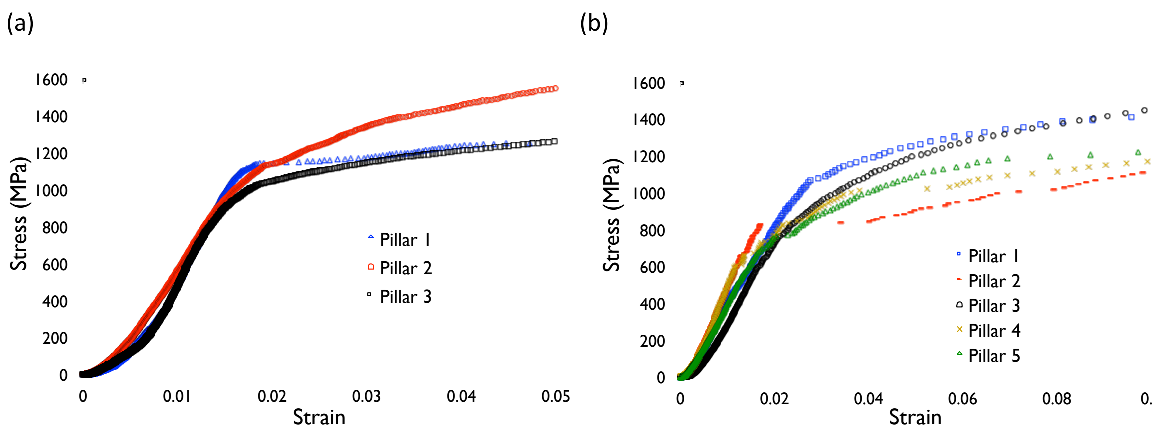

Figure 2: Micro-compressive stress-strain curves of (a) Ti-6-4 and (b) γ-TiAl

Material	Yield Strength	Young’s Modulus	Hardness
EBM Ti-6-4	1135 ± 12 MPa	114 ± 6 GPa	4.5 ± 0.3 GPa
Cast Ti-6-4	812 ± 26 MPa	116 ± 2 GPa	4.1 ± 0.2 GPa
EBM γ-TiAl	620 ± 21 MPa	179 ± 5 GPa	5.3 ± 0.2 GPa

Table 1: Mechanical properties of tested samples

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