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

Tait McLouth[1], Yuan-Wei Chang[1], John Wooten[2], Jenn-Ming Yang[1]

[1.] Department of Materials Science and Engineering, University of California, Los Angeles, U.S.A.
[2.] CalRam Inc., Simi Valley, CA, U.S.A.

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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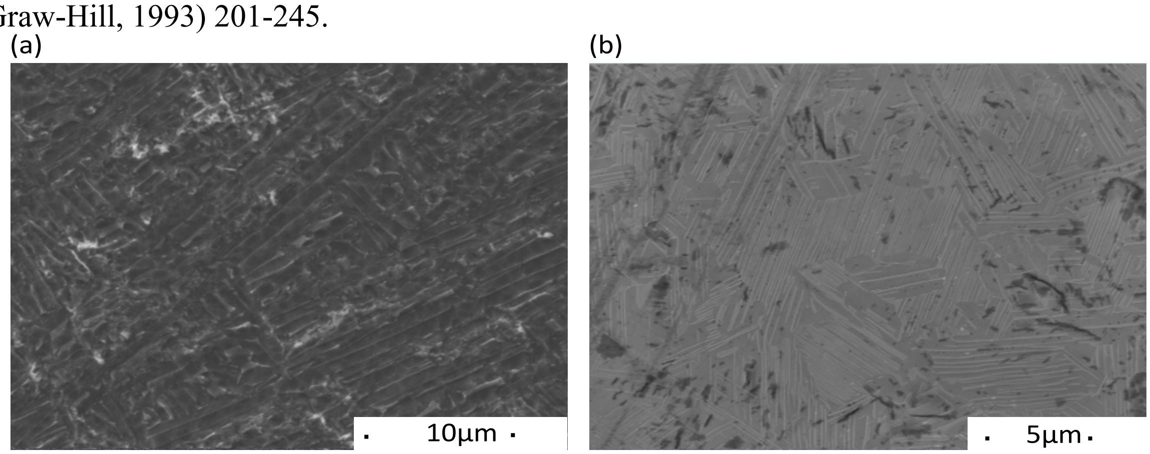

Figure 1: SEM images of microstructures for (a) Ti-6-4 showing the V rich β phase (lighter) and Al rich α phase (darker) and (b) γ-TiAl showing the α_2-Ti_3Al phase (lighter) and γ-TiAl phase (darker)

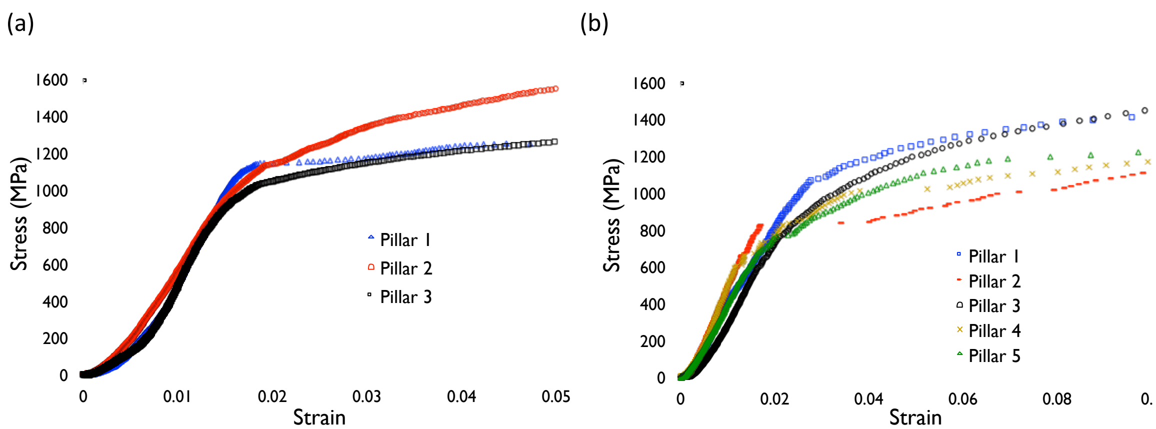

Figure 2: Micro-compressive stress-strain curves of (a) Ti-6-4 and (b) γ-TiAl

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