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Research Letter

Freeform Fabrication of Titanium Aluminide via Electron Beam Melting Using Prealloyed and Blended Powders

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Titanium aluminide (TiAl) is an intermetallic compound possessing excellent high-temperature performance while having significantly lower density than nickel-based superalloys. This paper presents preliminary results of experiments aimed at processing TiAl via the electron beam melting (EBM) process. Two processing routes are explored. The first uses prealloyed powder, whereas the second explores controlled reaction synthesis. Issues such as processing parameters, vaporization of alloying elements, microstructure, and properties are discussed.

1. INTRODUCTION

Titanium aluminide (TiAl) is an intermetallic compound that is valued for its light weight and high strength at elevated temperatures. These properties make it of considerable interest in the aerospace and automotive industries [1]. Unfortunately, the very properties that make the material useful in service also make it difficult to process via conventional methods. A number of researchers have therefore proposed the use of freeform fabrication techniques to produce TiAl structures to near net shape. One of such approaches involves using prealloyed powders with laser-based techniques to produce TiAl components to near net shape [2, 3]. Another approach is to use a laser to selectively induce reaction synthesis of elemental powder blends [4]. A more recent freeform fabrication technique uses an electron beam (EB) as the energy source rather than the laser. Each technique has advantages and disadvantages. EB-based systems tend to be capable of higher material deposition rates than laser-based systems; however, EB-based systems require a vacuum environment and must compensate for possible vaporization of alloying elements.

As the applications for TiAl tend to be in the aerospace and automotive industries, the components of interest tend to be large parts. The higher material deposition rate of EB-based systems, therefore, makes EB-based freeform fabrication of TiAl worthy of investigation.

2. ELECTRON BEAM MELTING OF PREALLOYED TiAl FEEDSTOCK

Electron beam melting (EBM) is a direct-metal freeform fabrication process in which an electron beam with a constant 60 kV acceleration voltage is used to selectively densify metal powder in a layerwise fashion to produce high density near net shape components [5]. The aim of this study was to evaluate the feasibility of fabricating titanium aluminide (TiAl) components to near net shape via the EBM process.

For the initial study, 50 kg of prealloyed −100/+325 mesh Ti-47Al-2Cr-2Nb powder was obtained from Crucible Research. A steel start plate having dimensions of 120 mm × 120 mm × 15 mm was placed in the vacuum chamber of an Arcam S12 EBM machine and then heated to a temperature of 900°C using the electron beam gun. A set of four test bars measuring 7.6 cm × 2.5 cm × 1.2 cm was fabricated side-by-side on the build platform (see Figure 1). For each layer, a 100 mm × 100 mm square area of powder was initially scanned for a total of 50 times using a beam velocity of 8,000 mm/s. From the first scan to the 50th scan, the beam current was linearly ramped up: 0.5 mA per scan from 1 mA to 25 mA. Then, the four rectangular areas to be melted (i.e., the four bars) were scanned for a total of 10 times at 2,000 mm/s while the beam current was linearly increased from 15 mA to 25 mA. This step lightly sintered the powder to be melted. At last, the four rectangular areas were melted

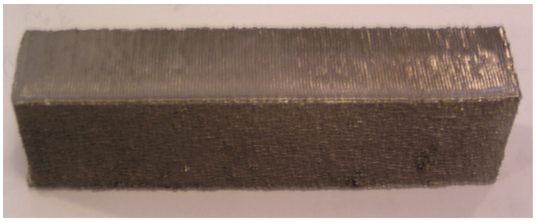


FIGURE 1: As-processed EBM TiAl test specimen.

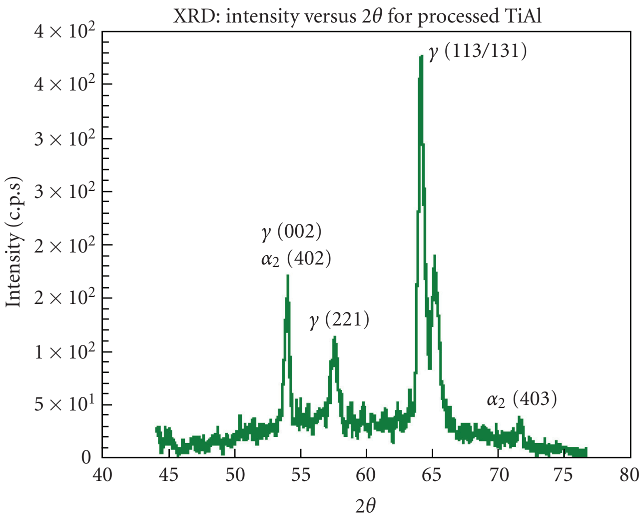


FIGURE 2: XRD pattern for the as-processed TiAl.

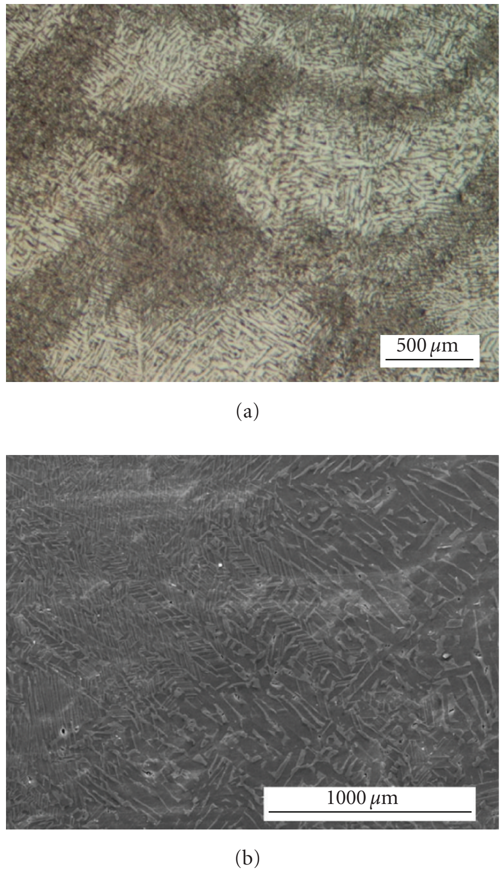


FIGURE 3: (a) Optical micrograph; (b) scanning electron micrograph.

in a single pass using a scan speed of 100 mm/s with a beam current of 13 mA. After each 100 μm thick layer of powder was melted, a new layer of powder was spread on top of the previous layer. The process was then repeated until the full part height was achieved.

2.1. *Elemental analysis*

Inductively coupled plasma (ICP) was used to determine elements present in the initial powder and the completed test bars. The powder was evaluated by NSL Analytical Services Incoroporation, and additional ICP analyses were conducted at NC State University. Table 1 summarizes these results. Approximately 6.1% of the aluminum vaporized during processing. The TiAl binary phase diagram suggests that TiAl with 25 wt% aluminum should have a microstructure consisting of $\alpha_2 + \gamma$ TiAl rather than just γ-TiAl. The X-ray diffraction (XRD) plot in Figure 2 confirmed that the EBM-processed TiAl contained both α_2 and γ TiAl phases.

2.2. *Microstructural analysis*

EBM-processed specimens were sectioned, mounted, polished, and then etched using Kroll's reagent (2% HF, 5% HNO_3, 93% H_2O). The specimens were observed via optical and scanning electron microscopy with the expectation of a lamellar $\alpha_2 + \gamma$ TiAl microstructure. Figure 3(a) shows a transverse-plane optical micrograph taken at 100X magnification. The layer thickness for this build was 100 μm; hence, approximately 20 layers worth of build height are shown. Complete interlayer fusion is quite evident. The microstructural effect of the electron beam traces resulting in coarse and fine lamellar $\alpha_2 + \gamma$ TiAl is easily identifiable. Figure 3(b) shows a representative transverse-plane SEM micrograph.

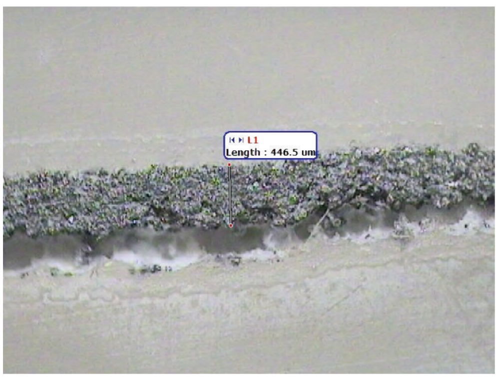
3. CONTROLLED REACTION SYNTHESIS OF TiAl

A second processing route under evaluation involved controlled reaction synthesis of elemental titanium and aluminum powders mixed in appropriate ratios. The powder used for these experiments was prepared by researchers at SIMTech in Singapore who have previously produced γ-TiAl by compacting mechanically alloyed titanium and aluminum powders in molds and then heating them to 660°C. The reaction is initiated as the aluminum reaches its melting point [6, 7]. The present study sought to determine whether or not electron beam parameters could be chosen such that the reaction would be locally controlled, thus, raising the interesting possibility of freeform fabrication via locally controlled reaction synthesis.

Table 1: ICP elemental analyses results.

Element	Powder composition		Final part composition	
	Weight %	Atomic %	Weight %	Atomic %
Ti	60.70	49.74	66.84	57.04
Al	31.76	46.20	25.62	38.83
Nb	4.87	2.05	5.17	2.27
Cr	2.65	1.99	2.32	1.82
Fe	0.03	0.02	0.05	0.04

(a)



(b)

Figure 4: Reaction synthesis results.

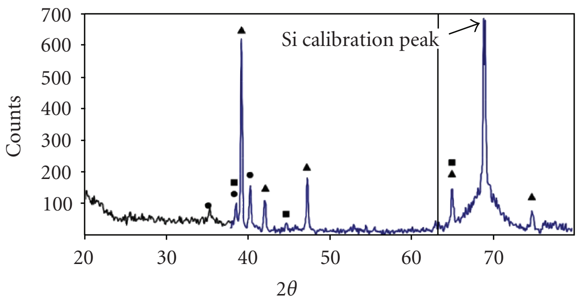


Figure 5: XRD patterns of reaction synthesis material.

The powder used was an equiatomic mixture of elemental titanium and aluminum powders that were mechanically alloyed via ball milling. A pocket measuring approximately 20 mm × 50 mm and 0.5 mm deep was created in a 100 × 100 × 15 mm stainless steel plate. The ball milled powder was spread in the pocket without compaction, the steel plate was placed in the EBM vacuum chamber, and the system was evacuated. The powder was directly preheated in a localized region on the powder bed using high scan speeds and a slowly increasing beam current (see Figure 4(a)). This was carried out until the reaction was visually identified by a sudden bright glow. A thin layer of titanium-aluminide was formed through reaction synthesis; however, there was still unreacted powder under the sheet (see Figure 4(b)).

XRD was used to determine the phases of the uncompacted titanium-aluminide obtained from the reaction synthesis. Figure 5 indicates that there are still small traces of unreacted titanium and aluminum that can most likely be attributed to loose powder beneath the reacted sample or due to unreacted powder between beam scan lines. The initial experiments show a clear peak of $TiAl_3$ at 39.4 counts per second, but there is no conclusive evidence of a predominant γ-TiAl phase. It is apparent that more detailed research is required to fully understand the controlled reaction synthesis and what needs to be done to achieve the more desirable γ-TiAl.

4. CONCLUSIONS AND FUTURE DIRECTIONS

The basic aim of this initial study was to investigate the feasibility of using the Arcam EBM process to fabricate TiAl to near net shape using two different EBM processing routes. EBM processing of prealloyed TiAl powder did successfully produce near net shape specimens. However, the vaporization of aluminum during processing resulted in a two-phase solid. It is expected that adjusting processing conditions to reduce vaporization and/or using powder feedstock with higher aluminum content could result in the desired single phase γ-TiAl.

The results of efforts to induce controlled reaction synthesis of elemental titanium and aluminum powders were mixed. Although locally controlled reaction synthesis was demonstrated, the resulting solid consisted primarily of $TiAl_3$ rather than the desired γ-TiAl. More experimentation will be needed to establish the feasibility of this particular processing approach.

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