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A novel method to fabricate TiAl intermetallic alloy 3D parts using additive manufacturing

J.J.S. Dilip [a, *], H. Miyanaji [a], Austin Lassell [a], Thomas L. Starr [b], Brent Stucker [c]

[a] Rapid Prototyping Center, Department of Industrial Engineering, University of Louisville, Louisville, KY 40292, USA
[b] Department of Chemical Engineering, University of Louisville, Louisville, KY 40292, USA
[c] 3DSIM, 1794 Olympic Parkway, Suite 110, Park City, UT 84098, USA

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ABSTRACT

The present work explores the feasibility of fabricating porous 3D parts in TiAl intermetallic alloy directly from Ti–6Al–4V and Al powders. This approach uses a binder jetting additive manufacturing process followed by reactive sintering. The results demonstrate that the present approach is successful for realizing parts in TiAl intermetallic alloy.

1. Introduction

Titanium-aluminides (TiAl) have low density (3.9 g/cm^3), good high temperature strength and superior resistance to oxidation (above 750 °C) giving them the potential to be used as light weight and high-temperature structural materials [1,2]. As such, these properties make the material quite attractive for aerospace and automobile applications. Recently, porous TiAl alloys are also being considered for high temperature liquid and gas separation filters [3]. TiAl alloys of technical significance have the general composition of Ti–Al (42–49) -X (0.1–1.0), where X represents alloying elements such as Cr, Nb, W, V, Ta, Si, B, and C [2,4]. Currently, large scale processing methods such as ingot casting, powder processing and ingot forging, sheet production by hot-rolling, powder metallurgy processing, investment casting and permanent mold casting are used to fabricate TiAl. However, these conventional methods pose significant challenges in processing of the alloy leading to higher production costs [1,2]. Given the ordered tetragonal structure and strong bonding between Ti and Al, the alloy is inherently brittle, making machining and shaping difficult [1]. To overcome such problems net-shape fabrication technologies such as powder metallurgy have been considered [2].

Additive manufacturing (AM) is advantageous for a number of reasons, including extensive design freedom in terms of geometry. Recent work have focused on the use of selective laser melting and electron beam melting AM processes to fabricate TiAl parts [5,6]. However, these processes encounter problems because they inherently involve melting and solidification stages. Also these processes suffer a variety of metallurgical problems such as solid state cracking due to thermal stresses from the inherent brittleness of as-cast TiAl microstructures [5–7]. In contrast, binder jetting avoids these problems as it is a low temperature process. In binder jetting powder is deposited layer by layer and binder is applied in the regions of interest, creating a green part directly from a CAD model. Subsequently, the green part from the printer is oven cured and sintered [7,8].

This study evaluates the feasibility of fabricating titanium aluminide (TiAl) parts by using Ti–6Al–4V and Al powders via binder jetting followed by a reactive sintering treatment. This route to produce TiAl intermetallic alloy parts can be economical when compared to the use of TiAl powders since TiAl powder is very expensive.

2. Materials and methods

In the present study two metal powders were used; atomized Al (Pyrochem, USA) and Ti–6Al–4V (Raymor-Grade 23) powders with

* Corresponding author.
E-mail address: samueldilip@gmail.com (J.J.S. Dilip).
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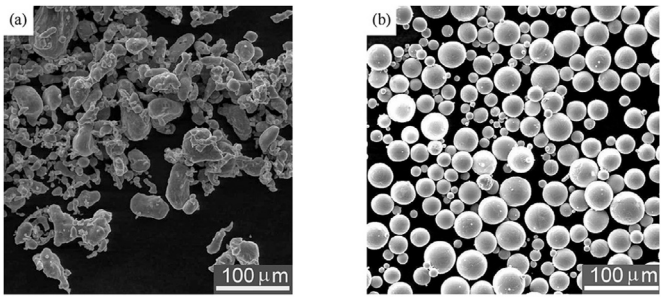

Fig. 1. SEM micrographs showing morphology of (a) Al powder and (b) Ti–6Al–4V powder used.

average particle size near 30 μm and 45 μm respectively. The powders were mixed in equi-atomic proportion (by Wt %) Al to achieve TiAl after sintering. The ExOne binder jetting printer was used to build 3D parts of 10 × 10 × 3 mm in size. The parameters used during binder jetting are as follows: 100 μm layer thickness, 60% binder drying power, 45 s dry time, jet feed rate 2 mm/min and 60% binder saturation level. The binder used for the experiment was "ExOne PM-B-SR1-04", an ether solvent based binder. The green parts from the printer were carefully loaded into an oven to cure the binder at 200 °C for 2 h. The cured parts were then subjected to reactive sintering at temperatures of 600 °C and 800 °C for 6 h, as well as 1000 °C for 6 h and 24 h in nitrogen atmosphere. Microstructural characterization of the powders and sintered parts was carried out using SEM equipped with EDS. Phase analysis of the steel powder and as-built samples were characterized using X-Ray Diffraction with Cu–Kα radiation ($\lambda = 1.54$ A°). The phases formed were identified by comparison of the recorded diffraction peaks with the ICDD database. Density of the sintered parts was measured using the Archimedes method according to ASTM B962-08.

3. Results and discussion

The size and morphology of the powders can be observed from the SEM micrographs presented in Fig. 1. The Al powder particles (Fig. 1(a)) are irregular in shape, whereas the Ti–6Al–4V alloy powder particles (Fig. 1(b)) are spherical in shape in a bimodal distribution.

Fig. 2(a) shows the samples sintered at different temperatures. The samples sintered at 600 °C appear bright (gray), whereas the samples sintered at higher temperatures appear black. This change in luster is attributed to the reaction products formed during sintering. The surface morphology of the sample sintered at 600 °C is presented in Fig. 2(b). The micrograph shows predominantly unreacted Al (irregular) and Ti–6Al–4V (spherical) particles. On any given Ti–6Al–4V particle, conical structures can be seen growing on the surface and interconnecting neighboring Ti–6Al–4V particles together. EDS analysis indicates these interconnecting channels have the composition of $TiAl_3$. Fig. 2(c) shows the surface morphology of a sample sintered at 800 °C for 6 h. Clearly, the surfaces of the particles appear different (grainier) than those sintered at 600 °C. The in-set in Fig. 2(c) shows a high magnification micrograph revealing the surface texture. Given the sintering

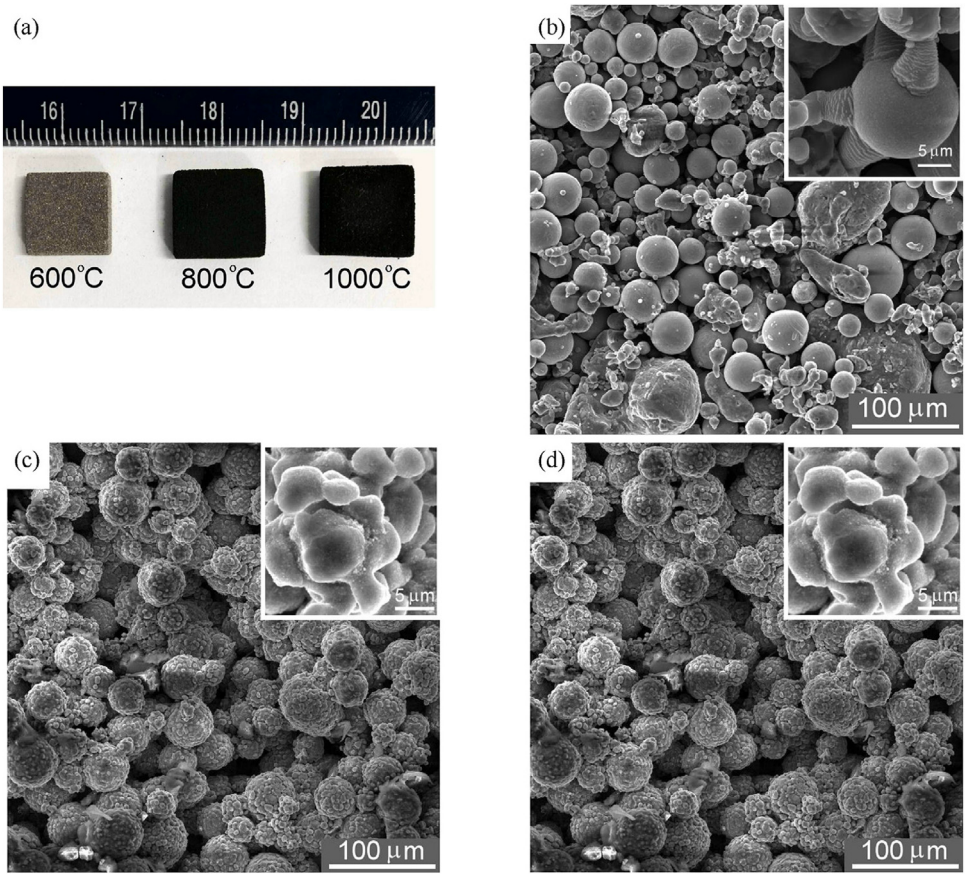

Fig. 2. (a) Photograph of sintered samples. SEM micrographs showing surface morphology of samples sintered for 6 h at 600 °C (b), 800 °C (c) and 1000 °C (d). High magnification micrographs are shown in the in-sets.