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Microstructural Development and Mechanical Properties of PM Ti–45Al–2Nb–2Mn–0.8 vol.%TiB_2 Processed by Field Assisted Hot Pressing

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A γ-TiAl intermetallic alloy, Ti–45Al–2Nb–2Mn (at.%)–0.8 vol.%TiB_2, has been processed from gas atomized prealloyed powder by field assisted hot pressing (FAHP). An initial analysis of the prealloyed powder helped on the understanding of the intermetallic sintering behavior. Atomized powder consisted of α metastable phase that transformed into $\alpha_2+\gamma$ equilibrium phases by thermal treating. Different powder particle microstructures were found, which influence the microstructure development of the FAHP γ-TiAl material depending on the sintering temperature. Duplex, nearly lamellar and fully lamellar microstructures were obtained at the sintering temperatures above 1000 °C. Lower consolidation temperatures, below 1000 °C, led to the formation of an Al rich phase at powder particle boundaries, which is deleterious to the mechanical properties. High compressive yield strength of 1050 MPa was observed in samples with FAHP duplex microstructures at room temperature. Whereas nearly lamellar and fully lamellar microstructures showed yield strength values of 655 and 626 MPa at room temperature and 440 and 425 MPa at 750 °C, respectively, which are superior in comparison to similar alloys processed by other techniques. These excellent properties can be explained due to the different volume fractions of the α_2 and γ phases and the refinement of the PM microstructures.

KEY WORDS: Titanium aluminides; Powder metallurgy; Microstructure; Mechanical properties; Field assisted sintering

1. Introduction

Titanium aluminides are important intermetallic alloys targeted for high temperature aerospace applications, namely the blades of low pressure turbines (LPT), because they can provide increased thrust-to-weight ratios and improve efficiency[1–4]. These blades must operate in aggressive environments at temperatures up to 750 °C, where titanium aluminides possess reasonably good creep and oxidation behavior[5–7]. It explains how such alloys have the potential to replace the heavier Ni-base superalloys currently used.

Two main approaches are currently being used in order to optimize the microstructure and mechanical properties by suitable alloy design and by choosing the proper processing route. Dual phase γ-TiAl alloys (γ-TiAl, tetragonal $L1_0$ structure and α_2-Ti_3Al, hexagonal DO_{19} structure) exhibit various microstructures consisting of different volume fractions of equiaxed grains and lamellar colonies. Depending on their microstructure, they are classified as duplex, nearly lamellar and fully lamellar. Lamellar microstructures make the material more resistant to creep conditions, while equiaxed grain microstructures are more ductile at room temperature[8,9]. Even though, single phase γ-TiAl alloys possess better ductility due to $L1_0$ structure, they show strong plastic anisotropy, prone to embrittlement due to oxygen contamination and poor fatigue resistance[8–10]. Therefore, extensive research has been carried out to achieve a two phase/multi phase microstructure (consisting γ-TiAl, α_2-Ti_3Al and β/B2) by varying Al concentration in the range of 42–48 at.% and by other alloying additions such as Cr, Nb, W etc[11–16]. Addition of Cr, Mn and V leads to an increase in ductility, while Nb, W, Mo and Ta increases the high temperature oxidation resistance, creep resistance and high temperature strength. In addition, alloying with B leads to a microstructure refinement.

The most popular processing routes that have been explored so far are a combination of casting, thermomechanical and/or

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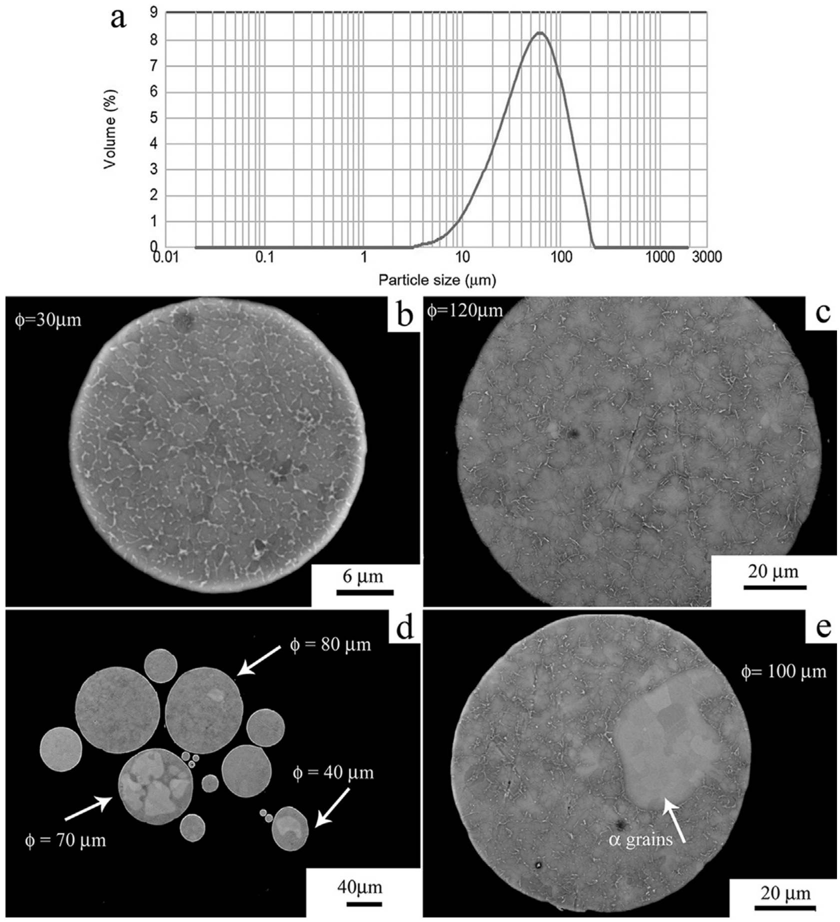

Fig. 1 (a) Powder particle size distribution and (b−e) backscattered (BSE) SEM micrographs showing the prealloyed powder microstructures for different particle's size: (b) 30 μm in diameter, (c) 120 μm in diameter and (e) 100 μm in diameter; (d) single phase regions present in particles of different sizes.

heat treatments and powder metallurgy (PM)[15,17−20]. Even though, casting is the best established process, which suffers from several drawbacks such as choosing proper composition in order to obtain good melt fluidity, casting defects, segregation of alloying elements, poor workability, need for post consolidation, heat treatments, etc[19,21]. To overcome some of these drawbacks several new techniques such as counter-gravity and centrifugal casting techniques have been developed, even then these techniques heavily depends on the prior knowledge of the equilibrium phase diagram and further optimization of heat treatments[15]. Compared to the casting route, PM offers several advantages such as refining the microstructure, improving structural and chemical homogeneity and providing freedom of choosing composition and initial raw materials, reducing the need to separate heat treatments and directly obtaining final product shape requiring minimal post processing treatments. Particularly, a wide variety of PM routes have been considered to develop γ-TiAl intermetallics. Starting from prealloyed powder benefits the microstructural homogenization and the mechanical properties. γ-TiAl prealloyed powder could be obtained by different gas atomization techniques, such as plasma inert-gas atomization (PIGA), titanium gas-atomizer process (TGA) or electrode induction gas atomization (EIGA) among others[22]. Since the prealloyed γ-TiAl powder particles present a significant hardness, cold compaction is replaced by hot consolidation techniques. In addition, the processing time can be reduced by using newer techniques known as field activated sintering (e.g., spark plasma sintering) where simultaneous application of pressure and pulsed/continuous direct/alternating current is used[23,24]. It has been found that the effect of the current is the fast generation of internal heat by Joule effect which increases the sintering kinetics[25,26], providing a rapid densification of powders and minimal grain growth. Extensive research is currently going on to process various compositions, to understand microstructure evolution, mechanical properties and upscaling to produce actual components by using field activated sintering techniques[14,19,27−36].

In the current work, a commercial Ti−45Al−2Nb−2Mn (at.%)−0.8 vol.%TiB_2 prealloyed powder has been sintered using one of the field activated sintering techniques known as field assisted hot pressing (FAHP), where simultaneous application of pressure and continuous alternating current is used. Different sintering temperatures have been selected to understand the microstructure development. Finally corresponding mechanical properties at room and elevated temperatures have been discussed.

2. Experimental

Prealloyed powder (Ti−45Al−2Nb−2Mn (at.%)−0.8 vol.% TiB_2) was employed as a raw material for the FAHP. The powder was gas atomized by EIGA at Helmholtz-Zentrum für Material