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ScienceDirect
Powder Technology 185 (2008) 124–130
POWDER TECHNOLOGY
www.elsevier.com/locate/powtec

Nanostructured titanium aluminides prepared by mechanical alloying and subsequent thermal treatment

S. Kumaran *, T. Sasikumar, R. Arockiakumar, T. Srinivasa Rao

Department of Metallurgical and Materials Engineering, National Institute of Technology, Tiruchirappalli, India-620 015

Received 8 September 2006; received in revised form 13 August 2007; accepted 14 October 2007
Available online 22 October 2007

Abstract

Ternary Ti–Al–Nb elemental powder blends with minor addition of SiC were synthesized in a high energy ball mill in order to understand the structural evolution during mechanical alloying (MA) and subsequent thermal treatment. X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM) techniques were employed to study the structural development during MA. Ti–48%Al–4%Nb–3%SiC and Ti–48%Al–8%Nb–3%SiC blends milled to 20 h were subjected to thermal treatment at 750 °C for 1 h in vacuum. Repeated cold welding and fracturing events of MA resulted in nanocrystalline structure with supersaturated solid solution and amorphous phase. The powder particles were also refined to submicron size due to high energy collision. The nanocrystalline supersaturated solid solution evolved by MA was sustained for prolonged milling time. There was no evidence of intermetallics formation even after early solid solubility extension and formation of nanocrystalline structure. However, nanostructured TiAl and Ti_3Al intermetallic compounds were observed after giving thermal treatment to MA powder blend. Since their surface area and energy were enhanced to a great extent, the dispersed ceramic particles reacted with titanium and formed nanosilicide particles.

Keywords: Mechanical alloying; Nanocrystalline structure; Amorphous phase; Titanium aluminides; Nanosilicide

1. Introduction

Light weight and high temperature performance of intermetallic compounds, in particular, aluminides, attracted the research community to shape the materials on par with super alloys. Nickel based super alloys are currently being used for engine turbines and for other critical high temperature applications. Though, these alloys are used in less quantity in aerospace related applications, they constitute nearly 30% weight of the structure. The aluminides such as nickel based, iron based and titanium based, were developed to reduce the overall weight of the aircraft structure so as to improve the engine performance. Ti–Al intermetallic compounds are considered to be one of the promising materials for aero engine because of its low density, high specific strength, stiffness, oxidation resistance, etc. But, they also exhibit like other intermetallic compounds with poor ductility and toughness. Improvement of these properties in aluminides would be possible by developing newer microstructures such as amorphous, nanostructure, quasicrystalline, etc. through mechanical alloying — non-equilibrium solid state, simple powder synthesis / processing technique [1–4]. Since the last three decades, different research groups focused their attention on developing newer materials / refining the characteristics of existing engineered alloys for various applications such as engine turbine, super corroding alloys, hydrogen storage alloys, soft magnets, bulk metallic glasses, etc [5]. Published results indicated significant improvement in the mechanical properties of Ti–Al intermetallics by major / minor ternary additions. It was shown that the additions of niobium, zirconium and magnesium substituted for titanium in the range of 2 to 6 at.% resulted in an increase in yield and fracture strengths of the Al-rich TiAl-base alloys [6]. Microstructural features of Ti–Al–Nb alloys (Ti–51.2%Al–5%Nb, Ti–48.4%Al–10%Nb and Ti–45.9%Al–15%Nb), mechanically alloyed, hot pressed and

* Corresponding author. Tel.: +91 431 2501801; fax: +91 431 2500133.
E-mail address: kumara@nitt.edu (S. Kumaran).

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doi:10.1016/j.powtec.2007.10.006

Table 1
Parameters used for this experiment

Mill	Planetary ball mill
Milling speed	Platen (250 rpm), Bowl (672 rpm)
Ball-to-powder ratio	10:1
Process control agent	1% Stearic acid
Environment	Ultra high purity argon (99.999)

annealed were reported elsewhere [7]. The microstructure obtained was a complicated one due to the presence of several phases. Niobium mostly dissolved in the γ-phase, replacing Ti. When Nb atom in the TiAl compound occupies Ti position, it leads to continuous ordering with increasing Al and Nb contents. This continuous ordering of compound results in to the formation of new ternary compound δ1-$Ti_4Nb_3Al_9$ [8]. The dispersoid containing samples exhibited high yield strength (1380 MPa) and considerable compressive ductility (11.5%) [9]. Finely dispersed Ti_5Si_3 in TiAl exhibited globular microstructure with the mean grain sizes in the nanometer or submicron range. These alloys fractured at 2940 MPa during compression [10]. Ti and Al powders milled in a heptane atmosphere when consolidated showed fine microstructures with an average grain size of a few hundred nanometers due to formation of $TiAl_2C$ [11]. Bohn et al. [12] reported nanocrystalline TiAl and Ti_3Al alloys with dispersion of Ti_5Si_3 by MA and followed by hot isostatic pressing. It has been proved that the formation of thermally stable dispersoid (silicides, carbides, etc) and incorporation of fine ceramic particulates inhibit the grain growth, but the ductility and toughness of the same is open to debate. There is limited work on addition of SiC in the Ti based intermetallics. The present work deals with the structural evolution of Ti–Al–Nb with small addition of SiC during MA and subsequent thermal treatment.

2. Experimental procedure

The objective of the present work was to understand the milling behaviour and related structural evolution during MA of elemental blend of ternary Ti–Al–Nb systems with minor atomic fraction of SiC and subsequent annealing. In order to achieve the above objective, two different elemental combinations, namely, Ti–48%Al–4%Nb and Ti–48%Al–8%Nb were identified. These two elemental powder blends with SiC (3 at.%) were synthesized in a high energy planetary ball mill (Make: Insmart Systems, Hyderabad, India). Since, the major constituents, titanium and aluminium are highly prone to oxidation, the powder handling (loading and unloading) was carried out in an inert atmosphere. The process parameters used in this study are listed in Table 1. Generally, temperature rise is expected during milling, which depends on type of mill, milling speed and milling operation. To avoid the temperature influence during milling, the milling operation was programmed such that the mill was operated for 10 min and kept idle for 20 min. More care was taken in processing of powders due to their physical and chemical nature. In spite of this, minute atmospheric contamination was observed. In fact it is difficult to obtain contamination free titanium based system synthesized through MA. It was also reported that the presence of contaminant elements (nitrogen, etc.) speed up the amorphization and in some cases, it may act as dispersion strengthener [13]. The powders collected at regular interval were subjected to structural analysis in order to understand the effect of milling time on developing newer structural aspects. SEM (Make: Jeol) was used to study powder morphology, particle size and distribution. The phase evolution and crystallite size of the MA and subsequent thermal treated

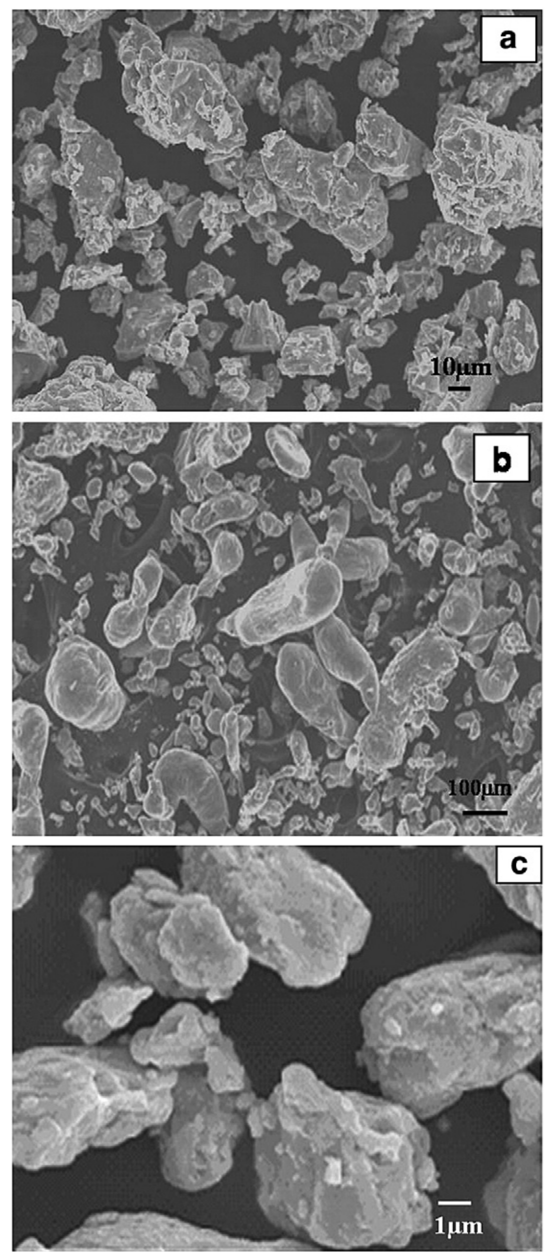

Fig. 1. SEM micrograph of elemental powders of a) Titanium, b) Aluminium and c) Niobium.