Intermetallics 98 (2018) 34–44

Contents lists available at ScienceDirect

Intermetallics

journal homepage: www.elsevier.com/locate/intermet

Processing, microstructure and mechanical properties of in-situ $Ti_3Al + TiAl$ matrix composite reinforced with Ti_2AlC particles prepared by centrifugal casting

J. Lapin[a,*], K. Kamyshnykova[a,b]

[a] Institute of Materials and Machine Mechanics, Slovak Academy of Sciences, Dúbravská cesta 9, 845 13, Bratislava, Slovak Republic
[b] Slovak University of Technology in Bratislava, Paulínska 16, 917 24, Trnava, Slovak Republic

ARTICLE INFO

Keywords:
Titanium aluminides
Composites
Casting
Heat treatments
Microstructure
Mechanical properties

ABSTRACT

The samples of in-situ $\alpha_2(Ti_3Al) + \gamma(TiAl)$ matrix composite reinforced with Ti_2AlC particles were prepared by a centrifugal casting of Ti-46.4Al-5.1Nb-1C-0.2B (at.%) alloy. The microstructure of the as-cast samples consists of equiaxed nearly lamellar $\alpha_2 + \gamma$ grains with ribbon like TiB particles formed in the interdendritic region and homogenously distributed plate-like Ti_2AlC particles distributed preferentially within the dendrites. The solution annealing of the samples in the α (Ti-based solid solution) phase field and subsequent air cooling (AC), oil quenching (OQ) and water quenching (WQ) leads to the formation of massive $\gamma_M(TiAl)$. The subsequent annealing in the γ phase field followed by a stabilisation annealing at 900 °C leads to the formation of homogeneous fine-grained γ type of microstructure in the OQ and WQ samples. The solution annealing of the OQ and WQ samples in the α phase field followed by slow cooling results in the formation of equiaxed grains with nearly lamellar $\alpha_2 + \gamma$ microstructure. The Vickers hardness and indentation elastic modulus strongly depend on the applied heat treatments. The in-situ composite with the coarse-grained lamellar microstructure shows improved creep resistance compared to that of some TiAl-based alloys with fully lamellar, nearly lamellar, convoluted or pseudoduplex microstructure.

1. Introduction

Cast TiAl-based alloys are attractive materials for industrial applications due to their light weight and excellent combination of properties at high temperatures [1–6]. These alloys allow reducing weight of aircraft engines and improve dynamic characteristics of turbochargers of combustion engines [2,4]. However, their inherent poor ductility at room temperature and insufficient strength at high temperatures (above 800 °C) limit their wide-scale applications. Intermetallic matrix composites may improve the deficiency of these alloys at high temperatures because of good combination of the properties of intermetallic matrix and reinforcement. Layered ternary MAX phases (M is a transition metal, A is an A-group element and X is nitrogen or carbon) such as Ti_2AlC and Ti_2AlN show a significant role in toughening and reinforcing of TiAl matrix composites [7–12]. Unique combination of both metallic and ceramic properties of Ti_2AlC including high fracture resistance, excellent damage tolerance, good thermal and electrical conductivity, easy machinability, good thermal shock and oxidation resistance, high elastic modulus and thermochemical stability benefit fabrication of in-situ composites [8–12].

Up to now, several techniques have been developed for processing components from TiAl-based alloys. The most promising are forging, powder metallurgy and casting. However, the forging is limited by chemical heterogeneity of initial ingots and powder metallurgy is quite expensive technology [13]. The most cost effective route for the production of complex shaped TiAl components such as turbocharger wheels, turbine blades or exhaust valves is precision casting [3,4,14–20]. Centrifugal precision casting leads to a better surface quality, no misruns in thin sections and less cracks compared to those of gravity cast components [3,17–23]. Centrifugal casting can be combined with different types of melting, but induction melting is the most frequently used technique due to its flexibility.

Cast ingots or near-shape castings prepared from TiAl-based alloys are usually characterised by a coarse-grained microstructure, sharp casting texture and significant chemical inhomogeneity. Imayev et al. [24] have shown that the TiAl-based alloys with a peritectic reaction/transformation are more predisposed for formation of inhomogeneous and coarse-grained microstructure during solidification. Various microstructure-properties related studies suggest that TiAl-based alloys with small grains and fine lamellar spacing are optimal for structural

* Corresponding author.
E-mail address: juraj.lapin@savba.sk (J. Lapin).

https://doi.org/10.1016/j.intermet.2018.04.012
Received 5 March 2018; Received in revised form 12 April 2018; Accepted 19 April 2018

applications [25]. There are two main approaches how to refine coarse-grained microstructure of as-cast alloys: (i) alloying with minor additions and (ii) solid-phase transformations during heat treatments [26–32]. According to the importance of diffusion, the solid phase transformations can be divided into two groups: (i) diffusionless massive transformation and (ii) diffusion-related transformations such as lamellar, Widmanstätten lamellar and feathery. Heat treatments inducing γ_M(TiAl) massive transformation are considered as a possible way to refine the grain size and reduce the texture without modifying shape of the cast components. A non-equlibrium microstructure consisting of γ_M grains exhibits high internal stresses and contains defects such as dislocations, stacking faults and anti-phase boundaries. Therefore, the γ_M needs to be subjected to tempering to obtain a stable microstructure [30].

The aim of this article is to study processing, microstructure and mechanical properties of in-situ $\alpha_2(Ti_3Al)$ + γ(TiAl) matrix composite reinforced with Ti_2AlC particles prepared by centrifugal casting of Ti-46.4Al-5.1Nb-1C-0.2B (at.%) alloy. In this alloy, niobium is added to improve oxidation resistance and strength properties at both room and high temperatures [33]. Boron refines grain microstructure, increases range of cooling rates for the formation of lamellar microstructure and promotes α phase (Ti-based solid solution with hexagonal crystal structure) to γ_M transformation during heat treatments [34–36]. Carbon improves creep resistance through the formation of fine Ti_2AlC or Ti_3AlC precipitates during heat treatments [37].

2. Experimental procedure

A master alloy with a chemical composition Ti-47Al-5.2Nb-0.2C-0.2B (at.%) was received in the form of vacuum arc remelted ingot with a diameter of 200 mm. The ingot was cut to smaller pieces with a diameter of 38 mm and length of 26 mm by wire electro-discharge machining. The charge was placed into a graphite crucibles with a diameter of 49 mm (outside diameter) and length of 75 mm. Each graphite crucible was put into a protective alumina crucible equipped with a pouring cup which was connected to a cylindrical graphite mould. The alloying of the master alloy by carbon was carried out during the melting in an induction furnace under protective argon atmosphere. After holding at a temperature of 1680 °C for 60 s the melt was centrifugally cast into the graphite mould at a rotation speed of 250 rpm. The centrifugally cast conical samples with a minimum diameter of 15 mm, maximum diameter of 17 mm and length of 150 mm were removed from the mould and subjected to a non-destructive inspection. The non-destructive testing was carried by 3D X-ray computer tomography (CT).

Hot isostatic pressing (HIP) was applied to remove casting porosity. The as-cast samples were put into alumina crucible, heated to a temperature of 1360 °C and hold at this temperature under a pressure of 200 MPa for 4 h in argon. The cooling of the HIP-ed samples to room temperature was carried out in the HIP apparatus at an average rate of 8 °C/min.

Heat treatment experiments were performed on the HIP-ed samples with a diameter of 16 mm and length of 30 mm. The heat treatments consisted of solution annealing at a temperature of 1405 °C for 1 h under protective argon atmosphere followed by a cooling in three different mediums: forced air, oil and water. Each cooling step was followed by the annealing. The annealing experiments were carried out either at a temperature of 1225 °C for 4 h followed by stabilisation annealing at a temperature of 900 °C for 20 h in air or at 1360 °C for 30 min followed by cooling at a rate of 10 °C/min in argon.

Instrumented hardness measurements were performed by universal hardness testing machine. Martens hardness test was carried at an applied load of 50 N, holding time at the point of load application of 2 s and speed of load application was of 15 N/s on the samples after centrifugal casting, HIP and heat treatments.

Cylindrical creep specimens with a gauge diameter of 6 mm and gauge length of 30 mm were lathe machined from both the centrifugally cast in-situ composite and as-received Ti-47Al-5.2Nb-0.2C-0.2B (at.%) alloy after HIP at 1360 °C for 4 h and stabilisation annealing at 900 °C for 20 h. Constant load tensile creep tests were carried out at four temperatures of 800, 850, 900 and 950 °C under an initial stress of 200 MPa in air. The test temperature was monitored with two thermocouples touching the specimen gauge section and held constant within ± 1 °C. Elongation was measured using a high temperature extensometer attached to the ledges of the creep specimen. The extensometer was equipped with a linear variable displacement transformer (LVDT). The acquisition of time-elongation data was accomplished by a computer and data processing was performed by a computer program.

Metallographic preparation of the samples consisted of standard grinding using abrasive papers, polishing on diamond pastes with various grain size up 1 μm and etching in a solution of 100 ml H_2O, 6 ml HNO_3 and 3 ml HF. Microstructure evaluation was performed by optical microscopy (OM), scanning electron microscopy (SEM) and scanning electron microscopy in back scattered electron (BSE) mode. Chemical composition of the samples was analysed by energy-dispersive spectrometry (EDS). X-ray diffraction (XRD) analysis was carried out by a diffractometer equipped with X-ray tube with rotating Cu anode operating at 12 kW. Average content of carbon in the in-situ composite was measured by LECO CS844 elemental analyser. Oxygen content was measured with a LECO ONH836 elemental analyser. Volume fraction of phases and grain size were measured by computerised image analysis using digitalised micrographs and measured data were treated statistically.

3. Results and discussion

3.1. Microstructure of as-cast in-situ composite

Figs. 1 and 2 show the example of centrifugally cast in-situ

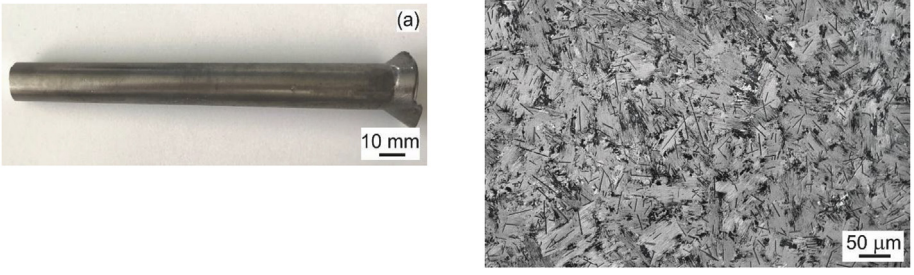

Fig. 1. OM micrographs of centrifugally cast in-situ composite: (a) as-cast conical sample with a feeding head; (b) transverse section showing equiaxed grain microstructure.