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High strength Ni based composite reinforced by solid solution W(Al) obtained by powder metallurgy

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Abstract

The solid-solution-particle reinforced W(Al)–Ni composites were successfully fabricated by using mechanical alloying (MA) and hot-pressing (HP) technique when the content of Ni is between 45 wt% and 55 wt%. Besides, samples of various original component ratio of $Al_{50}W_{50}$ to Ni have been fabricated, and the corresponding microcomponents and mechanical properties such as microhardness, ultimate tensile strength and elongation were characterized and discussed. The optimum ultimate tensile strength under the experiment conditions is 1868 MPa with elongation of 10.21% and hardness of 6.62 GPa. X-ray diffraction (XRD), FE-SEM and energy dispersive analysis of X-rays (EDS) were given to analysis the components and morphology of the composite bulk specimens.

Keywords: W(Al)–Ni composites; Solid-solution-particle; Mechanical properties

1. Introduction

Much research work has been carried out in the field of structural materials of composite during recent decades. The promise of composites lies in their multifunctionality, the possibility of realizing unique combinations of properties unachievable with conventional materials [1]. Particle-reinforced composites, which possess high elastic modulus and strength, have been widely used in the aerospace and automobile industries [2,3]; fiber-reinforced titanium matrix composites are reviewed with respect to application needs for advanced high-temperature aerospace materials [4]. Hard brittle materials like intermetallic or ceramic have been bonded by metal phase with high tenacity and fine wettability to form high strength and hardness materials [5,6].

In the last few years, the supersaturated aluminium–tungsten solid solution powders had been produced by mechanical alloying (MA) [7]. The maximum solid solubility of Al achieved was up to 86 at.% and the Al–W alloys were found out a kind of promising material due to its attractive excellent properties such as low density, high hardness, high strength and excellent corrosion/oxide resistance [8]. Besides, the mechanical properties of $Al_{50}W_{50}$ alloy bulk bodies fabricated by mechanical alloying and hot-pressing have been reported. The alloy had excellent thermal stability up to 1300 °C under vacuum and its optimum microhardness, bending strength and compressive strength were 10.21 GPa, 570 MPa and 2.07 GPa, respectively [9].

$Al_{50}W_{50}$ alloy possessing outstanding features mentioned above should be another potential reinforcement in structural composites, although taking solid solution alloy as reinforcement to MMC is seldom reported. It would be of great interest and importance to obtain a kind of high strength and ductile materials by compounding $Al_{50}W_{50}$ with flexible and wetable phase, which is supposed to provide ductility in the composite.

On the other hand, the small-particle can be homogeneously mixed by MA, an effective fabrication process for preparing such materials by uniformly dispersing fine particles into the alloy body [10–12]. Furthermore, since property improvement is greatly associated with microstructure, hot-press (HP) sintering was employed for the manufacturing of the composite bulk bod-

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ies to minimize grain growth hence prepare a fine microstructure. Therefore, the combining of MA and HP has been performed as a fabrication process to develop advanced composite with improved mechanical properties [13].

Herein, we select $Al_{50}W_{50}$ as the original strengthening phase to compound with Ni to obtain series W(Al)–Ni composites bulk bodies via MA-HP process. Additionally, the structure and mechanical properties of the resulting samples are characterized and analyzed.

2. Experimental procedures

2.1. Preparation

The supersaturated substitutional solid solution $Al_{50}W_{50}$ nanocrystalline alloy is synthesized by mechanically alloying the pure metal powders mixture for 30 h [7]. The alloyed powder $Al_{50}W_{50}$ (<0.1 μm, 99% purity) was then used as raw materials to mix with commercial grade nickel (58 μ, 99.6 wt%) powder in different weight ratio and then mechanically milled for 2 h in a stainless steel vial filled with argon. Mechanical alloying was performed on GN-2 high-energy ball mill with a rotation speed of 580 rpm. The ball to powder weight ratio was 10:1, and diverse diameter balls (12–7 mm) were used for improving efficiency of milling. Process control agent (PAC) was added for protecting the increased Ni phase from cold welding. In order to avoid oxidation of powders during MA treatment, all the handling was performed under argon atmosphere in a glove box.

The composite powders were then cold-pressed into a green compact and sintered in an inductive hot-pressing vacuum furnace with the following process: (a) heated from room temperature to sintering temperature 1480 °C with a heating rate of about 120 °C/min; (b) kept the sintering temperature for 60 min; (c) cooled down from the sintering temperature to 600 °C at about 150 °C/min, and then furnace cooled from 600 °C to room temperature. The pressure in the die was kept at 40 MPa and the vacuum degree was 80 Pa in the furnace. Then the obtained bulk specimens were grinded and polished. We denoted the samples as follows: AW–Ni*x* series stands for the W(Al)–Ni composite, where *x*% is the content of Ni by weight.

2.2. Characterization

The densities of the sintered specimens were determined by the Archimedes water immersion method. Vickers hardness was measured by the Leitz-Wetzlar Miniload II apparatus with a load of 200 g and duration of 15 s. UTS test was performed on an Instron model 1125 test machine at a crosshead speed of 2 mm/min. Structural analysis were performed by X-ray diffraction (XRD) on a Rigaku D/max 2500PC X-ray diffractometer with Cu Kα radiation (λ = 1.54056 Å). The field emission scanning electron microscope (FE-SEM, Philips, XL30) and the energy dispersive analysis of X-rays (EDS) measurements were conducted to investigate the morphology and the quantitative material composition of the sample.

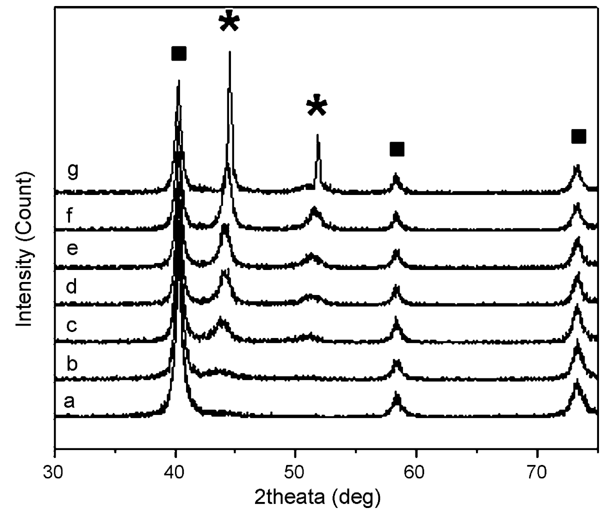

Fig. 1. XRD patterns of (a) AW–Ni16, (b) AW–Ni30, (c) AW–Ni45, (d) AW–Ni55, (e) AW–Ni65 and (f) AW–Ni75 after milling for 2 h and (g) AW–Ni45 raw powder (squares: $Al_{50}W_{50}$ and asterisks: Ni).

3. Results and discussion

3.1. XRD patterns of W(Al)–Ni composites

Fig. 1 shows the XRD patterns of (a) AW–Ni16, (b) AW–Ni30, (c) AW–Ni45, (d) AW–Ni55, (e) AW–Ni65 and (f) AW–Ni75 powders after 2 h milling from blended raw powders as well as that of (g) AW–Ni45 raw powders, respectively. It can be seen clearly that intensity of Ni peaks increase with the increasing content of Ni from (a) to (f), and Ni peaks are broadened in each XRD patterns with all the peaks positions of Ni showing a certain shift to the small angle side compared with those of (g). Here we take diffraction data to calculate the crystallite size according to the Scherrer formula: $D_{hkl} = K\lambda/\beta\cos\theta$, where λ is the X-ray wavelength (0.15405 nm), β the full-width at half-maximum, θ the diffraction angle, K is a constant (0.89) and D_{hkl} means the size along (hkl) direction [14]. The average crystallite size of Ni estimated is around 50.8 nm in AW–Ni45 raw material and 13.3 nm in 2 h-milling AW–Ni45, which confirmed that peak broadening is associated with the refinement of the crystallite size, and the small crystalline size makes the blended powders uniformly distributed possible. The shift towards low angle side suggests the dissolving of certain $Al_{50}W_{50}$ in Ni after 2 h milling, which might be attributed to the increased lattice parameters caused by solution of Al, W in Ni phase. As the initial ratio of $Al_{50}W_{50}$ to Ni decreased from (a) to (f), the saturation degree of Ni solid solution decreased, thus the offset of peaks positions of Ni decreased as the XRD patterns show. It is obvious that the ball-milling is beneficial to reduce the crystallite size by introducing internal strain and large grain boundary fraction, which can serve as driving forces for accelerating the sintering in the following hot-pressing process.

The XRD of the samples of AW–Ni16, AW–Ni30, AW–Ni45, AW–Ni55, AW–Ni65 and AW–Ni75 after 60 mins HP sintering are given in Fig. 2(a–f), respectively. It can be seen that when the content of Ni is between 45 wt% and 55 wt% (Fig. 2(c