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Deformation behaviour of a newer tungsten heavy alloy

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ABSTRACT

The present study attempts to investigate room temperature and high temperature flow behaviour of a tungsten heavy alloy (W-7.10Ni–1.65Fe–0.5Co–0.25Mo alloy). The alloy was deformed under compression at room temperature and elevated temperatures (400–700 °C) at different strain rates (1–0.0001 s^{-1}) to observe plasticity under compression loading at these temperatures and strain rates. The alloy showed higher plasticity and positive strain rate sensitivity at room temperature. Samples hardness after 70% deformation at room temperature increased from 3.20 ± 0.14 to 5.08 ± 0.03 GPa. Barreling was observed in room temperature compression tested samples. Microstructure of the alloy after heavy compressive deformation at room temperature showed that severe deformation of W grains took place along a direction at 45° to the direction of applied stress. The alloy showed varying (positive and negative) strain rate sensitivity at elevated temperatures. Samples hardness after 70% deformation at elevated temperatures increased from 3.20 ± 0.14 to 4.60 ± 0.23 GPa. At 600 and 700 °C, the specimens failed by shear along the direction which is at an angle 45° to the direction of applied stress. Microstructural evidences indicate that the failure at these elevated temperatures seems to be triggered by the excessive void generation in the matrix and their coalescence under the influence of the applied stress. Room temperature deformation mechanism of tungsten heavy alloy was also studied by carrying out tensile testing at room temperature in strain rates ranging from 0.1 to 0.0001 s^{-1}. The values of strain rate sensitivity, and apparent activation volume with respect to different level of strain suggest that the deformation mechanism of the alloy is similar to that of bcc metals such as tungsten and molybdenum, i.e. Peierls mechanism controls the dislocation motion.

1. Introduction

Tungsten heavy alloys (WHAs) is a composite where the rounded bcc tungsten grains are cemented by a ductile and relatively low melting fcc matrix phase [1]. These alloys find wide applications as centre of gravity (CG) adjuster, radiation shields, kinetic energy penetrators (KEP), etc. [2–4] because of their high density and very superior tensile properties and toughness values.

The strength, density and hardness of these alloys largely depend on the chemistry of the alloy. Bose et al. [5] and German et al. [6] showed that lowering the tungsten (W) content in the alloys up to 90 wt.% causes an improvement in the ultimate tensile strength as well as elongation value of the sintered WHAs. However, Gero et al. [7] and Humail et al. [1] observed that tensile strength of WHAs slightly decreases (although elongation value increases) with lowering of tungsten content.

Gero et al. [7] observed that the WHAs showed higher plasticity under compression loading than that under tensile loading. He also explained that the highly deformed WHAs can be achieved by compression loading usually by forging. These highly deformed alloys showed higher tensile strength than the undeformed alloys [7]. Bose et al. [5] also observed that the 92.5%W-(Ni–Fe–Co) alloy deformed up to 95% showed a tensile strength of 1720 MPa with concomitant elongation of 16%. Peter Skoglund [8] showed that the tensile strength of the alloys can be increased at room temperature by increasing the tensile strain rate.

Although several of the above literatures thoroughly explained the reason behind the improvement in tensile properties by lowering the tungsten content as well as by cold deformation (forging), studies on the flow behaviour are very scarce [9]. However, Understanding of the flow behaviour of WHAs is extremely important in order to develop alloys with superior mechanical properties. While studies have been carried out to understand room and low temperature deformation mechanism in pure tungsten [10], such studies in tungsten heavy alloy – two phase aggregate of bcc tungsten grains and fcc matrix phase – are only a few [9].

Erwin Pink and Subodh Kumar [9] explained that the double kink mechanism – which is typical in bcc tungsten – is the rate controlling mechanism of tungsten heavy alloy below 400 °C. However,

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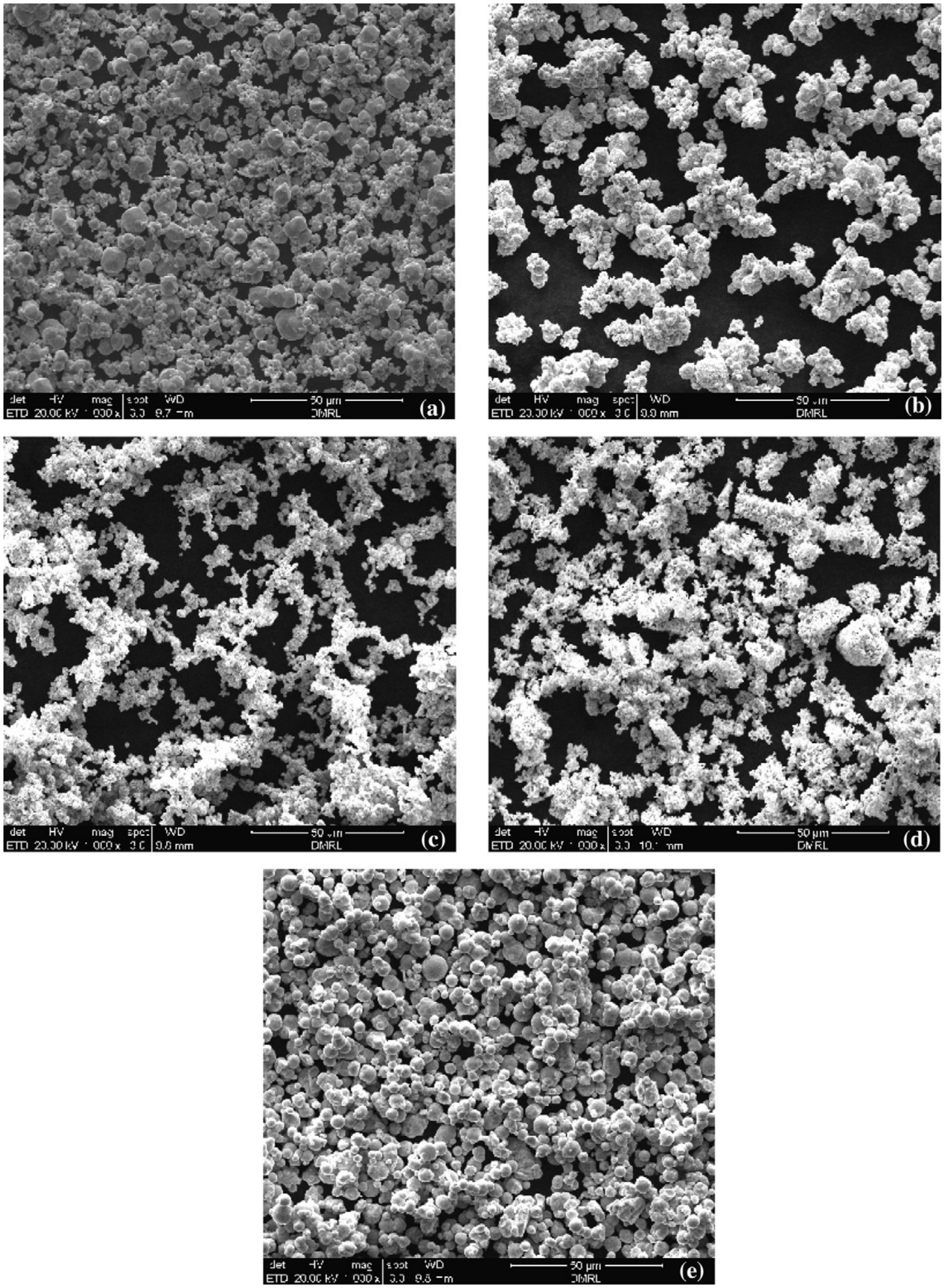

Fig. 1. Scanning electron microscopy (SEM) images of precursor powders of (a) Mo, (b) W, (c) Ni, (d) Co and (e) Fe which are used for making tungsten heavy alloy.

strain rate sensitivity (SRS) of tungsten heavy alloy below 200 °C was found to be dependent on the strain level due to presence of fcc matrix phases. Although they plotted SRS at different strain level at −50 °C, 0 °C, 90 °C and 112 °C, respectively, they did not plot the same at room temperature. In order to observe the rate controlling mechanism at room temperature, tensile tests of tungsten heavy alloy (W-90.5%, Ni–Fe–Co–Mo-9.5%) were conducted at room temperature. Applied strain rates were in the range of 0.1–0.0001 s^{-1}. Strain rate sensitivity (SRS), strain rate sensitivity index (m) and activation volume (Ω_{act}) at a true strain ranging between 0.01 and 0.1 were calculated.

In order to study the flow behaviour of the alloy at room temperature and elevated temperature (up to 700 °C) under compression loading, compressive tests both at room temperature as well as at elevated temperatures (400–500–600–700 °C) were also carried out. The tests were carried out at different strain rates (ranging from 1.0 to 0.0001 s^{-1}). A highly ductile (1000 MPa strength, 30% elongation at room temperature)