Journal of Alloys and Compounds 434–435 (2007) 433–436

Journal of ALLOYS AND COMPOUNDS

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Effect of mechanical alloying process on microstructure and mechanical properties of ODS tungsten heavy alloys

Kyong H. Lee [a], Seung I. Cha [a], Ho J. Ryu [b], Morris F. Dilmore [c], Soon H. Hong [a,*]

[a] Department of Materials Science and Engineering, Korea Advanced Institute of Science and Technology, 373-1 Kusung-dong, Yusung-gu, Daejeon 305-701, Republic of Korea

[b] DUPIC, Korea Atomic Energy Research Institute, 150 Deokjin-dong, Yusung-gu, Daejeon 305-353, Republic of Korea

[c] Air Force Research Laboratory, Eglin Air Force Base, FL 32542-1405, USA

Available online 16 October 2006

Abstract

The microstructure and mechanical properties of mechanically alloyed oxide dispersion strengthened (ODS) tungsten heavy alloys were investigated. Three different mechanical alloying processes, such as one-step mechanical alloying process, two-step mechanical alloying process, and mechanical alloying and mixing process, were performed in order to control the microstructure and mechanical properties of ODS tungsten heavy alloys. The partially stabilized zirconia (PSZ) dispersoids tend to be dispersed in tungsten grains rather than the binder matrix when the powders were prepared by two-step mechanical alloying or mechanical alloying and mixing process. The yield strength of ODS tungsten heavy alloy increased with decreasing the binder mean thickness, but was not dependent on location of oxide dispersoids. The elongation and high temperature strength of ODS tungsten heavy alloys increased with increasing the content of PSZ dispersoids.

Keywords: Tungsten heavy alloy; Oxide dispersion strengthened (ODS); Mechanical alloying (MA); Microstructure; Mechanical properties

1. Introduction

Tungsten heavy alloys, consisting of 88–97 wt.% of bcc W particles and fcc W–Ni–Fe alloy matrix, are used as kinetic energy penetrators, counter weight balances, radiation shields and vibration damping devices due to their high density, excellent strength and good ductility [1,2]. Research to improve the penetration performance of tungsten heavy alloy have been carried out for replacement of depleted uranium, which has superior penetration performance with radioactive contamination problems [3–15].

In order to enhance the penetration performance of tungsten heavy alloy, several methods are proposed including W grain size control [10], alloying with Mo and Re [13], solid state sintering of mechanically alloyed powder [10,11], surface carburization [14], cyclic heat treatment [15] and oxide dispersion strengthening [11,12]. Among those methods, the oxide dispersion strengthening shows a change of dynamic fracture mode from adiabatic shear band to brittle fracture and is considered as improvement mechanism in penetration performance of tungsten heavy alloy [12]. However, ODS tungsten heavy alloys have shown lower ductility than conventional tungsten heavy alloys. Tensile strength and elongation are important factors for their penetration performance. In addition, elongation is an important factor for working processes including the swaging process. Therefore, it is significant to develop the ODS tungsten heavy alloys with good ductility for improved penetrator application.

In this study, the location of oxide dispersoids was controlled by a modification of mechanical alloying process in order to improve the elongation of ODS tungsten heavy alloys. In addition, the yield strength and high temperature compressive strength were investigated with varying the oxide content and location of oxide dispersoids.

2. Experimental procedures

The elemental powders of W, Ni, Fe and partially stabilized zirconia (PSZ, stabilized by 3 wt.% of Y_2O_3) were mechanically alloyed to fabricate ODS tungsten heavy alloys powders. The composition of tungsten heavy alloy was designed as 94W–(6 − x)(Ni,Fe)–xPSZ with fixed Ni/Fe weight ratio of 4:1 and with PSZ content ranged 0–0.5 wt.%. The mechanical alloying was carried out using a planetary mill. In order to control the location of oxide dispersoids, three different mechanical alloying processes were designed including one-step mechanical alloying process, two-step mechanical alloying process and mechanical alloying and mixing process. Zirconia balls with diameter of 10 mm were

* Corresponding author. Tel.: +82 42 869 3327; fax: +82 42 869 3310.
E-mail address: shhong@kaist.ac.kr (S.H. Hong).

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doi:10.1016/j.jallcom.2006.08.284

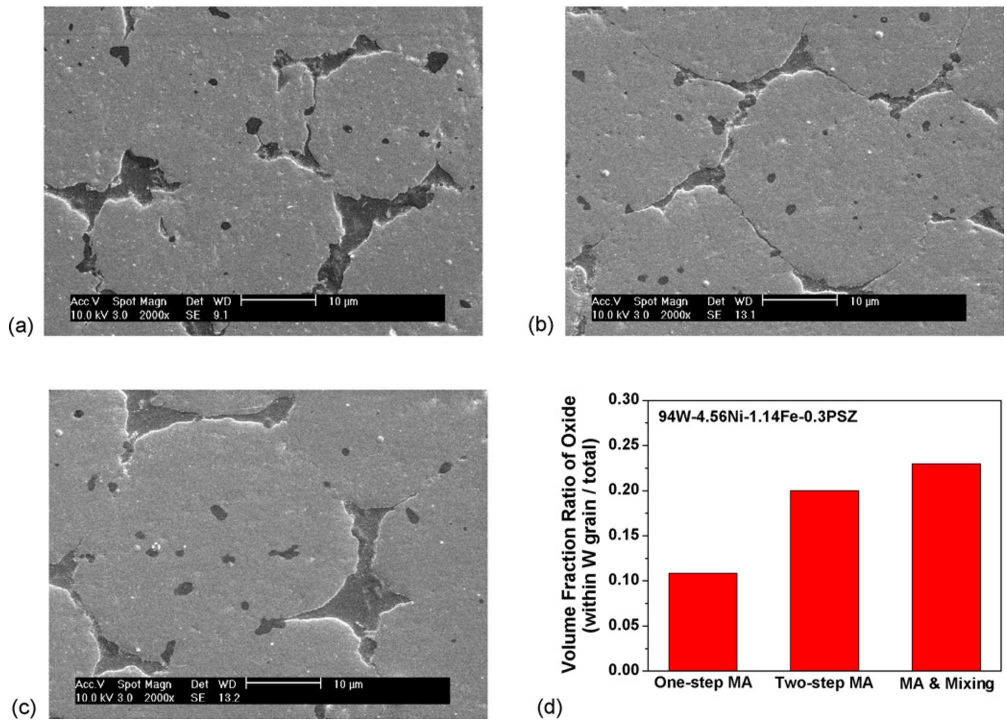

Fig. 1. SEM Micrographs of 94W–4.56Ni–1.14Fe–0.3PSZ tungsten heavy alloys sintered at 1485 °C for 1 h using the powders prepared by: (a) one-step mechanical alloying process, (b) two-step mechanical alloying process, and (c) mechanical alloying and mixing process. (d) Variation of volume fraction ratio of PSZ dispersoids within tungsten grain to total PSZ dipersoids with varying the mechanical alloying process.

used for mechanical alloying. The powders were mechanically alloyed with a rotation speed of 200 rpm and ball-to-powder ratio of 10:1 for 6 h.

The mechanically alloyed ODS tungsten heavy alloy powders were consolidated by liquid phase sintering in hydrogen atmosphere for 1 h at 1485 °C. The sintered alloys were heat treated at 1150 °C for 1 h in nitrogen atmosphere followed by water quenching in order to avoid hydrogen embrittlement and segregation of impurities such as P and S [16,17]. The variation of microstructural parameters was measured by optical and scanning electron microscopy. Tensile tests were performed using an Instron 5583 testing machine under a strain rate of $6.67 \times 10^{-4}\ s^{-1}$. High temperature compressive tests were carried out using a hot working simulator (Thermecmaster-Z) at 800 °C under a strain rate of $10\ s^{-1}$ in a vacuum of 10^{-3} Torr.

3. Results and discussion

3.1. Effect of mechanical alloying process on microstructures of ODS tungsten heavy alloys

Modified mechanical alloying processes were applied to control the location of oxide dispersoids in ODS tungsten heavy alloys. Tungsten and PSZ powders were mechanically alloyed as a first step. Then mechanically alloyed tungsten/PSZ powder was milled again with Ni and Fe powders for two-step mechan-

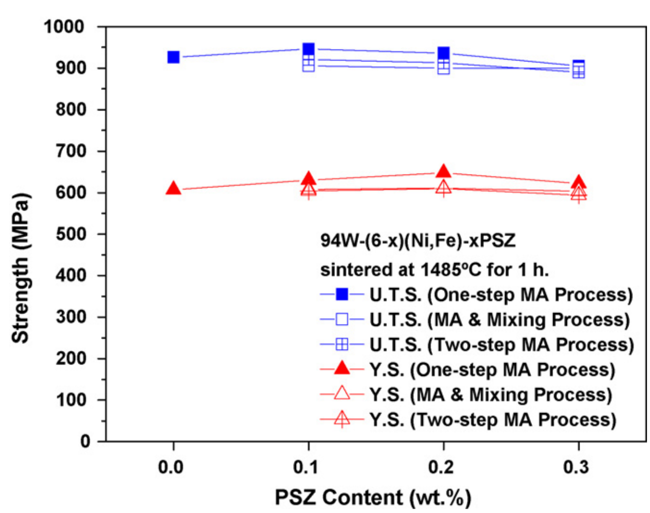

Fig. 2. Variation of yield strength and ultimate tensile strength of ODS tungsten heavy alloys sintered at 1485 °C for 1 h with varying PSZ content.

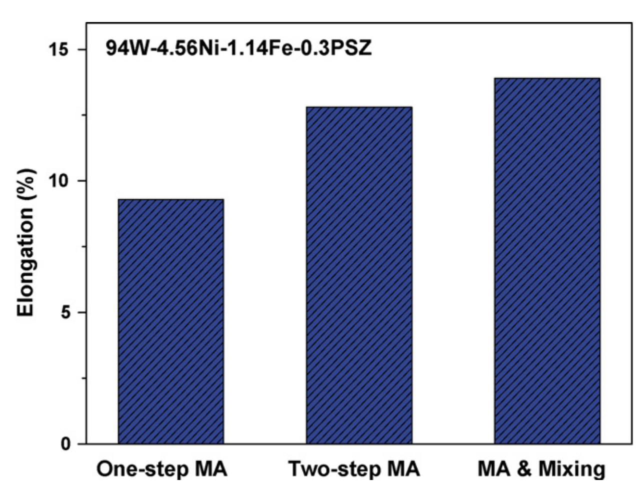

Fig. 3. Comparison of the elongation of ODS tungsten heavy alloys sintered at 1485 °C for 1 h using the powders prepared by three different mechanical alloying processes.

ical alloying process. For mechanical alloying and mixing process, mechanically alloyed tungsten/PSZ powder was mixed with Ni and Fe elemental powders without further milling. Fig. 1 compares the microstructures of ODS tungsten heavy alloys sintered at 1485 °C for 1 h using the three different mechanical alloying processes. The oxide dispersoids were located within tungsten grains as well as at tungsten/tungsten and tungsten/matrix interfaces, and in the matrix by one-step mechanical alloying process. However, the fraction of oxide dispersoids located within tungsten grains increased by two-step mechanical alloying process or mechanical alloying and mixing process compared with conventional one-step mechanical alloying process as shown in Fig. 1(d).

3.2. *Effect of mechanical alloying process on mechanical properties of ODS tungsten heavy alloys*

Variation of yield strength and ultimate tensile strength of ODS tungsten heavy alloys prepared by three different mechanical alloying processes with various PSZ content are shown in Fig. 2. The yield strengths and ultimate tensile strengths (UTS) were about 600 MPa and 900 MPa, respectively, and were not sensitive to oxide content or different mechanical alloying processes, i.e. the location of oxide dispersoids.

However, the elongation of ODS tungsten heavy alloys was sensitively dependent on location of oxide dispersoids controlled by modified mechanical alloying processes. ODS tungsten heavy alloys sintered from the powders prepared by two-step mechanical alloying process or mechanical alloying and mixing process, which has higher oxide dispersoids content within tungsten grains compared to conventional one-step mechanical alloying process, showed higher elongation as shown in Fig. 3.

High temperature compressive yield strength of ODS tungsten heavy alloy gradually increased from 345 MPa to 1000 MPa with increasing amount of PSZ content up to 5 wt.% as shown in Fig. 4. These values are higher than that of conventional tungsten heavy alloy, which is about 340 MPa under the same testing condition. These results indicate that the dispersion strengthening of the oxide at high temperatures inhibits the deformation of the tungsten heavy alloy and addition of the PSZ dispersoids effectively enhances the high-temperature compression strength. It is known that enhancement of high temperature strength is an important factor to improve the penetration performance [12].

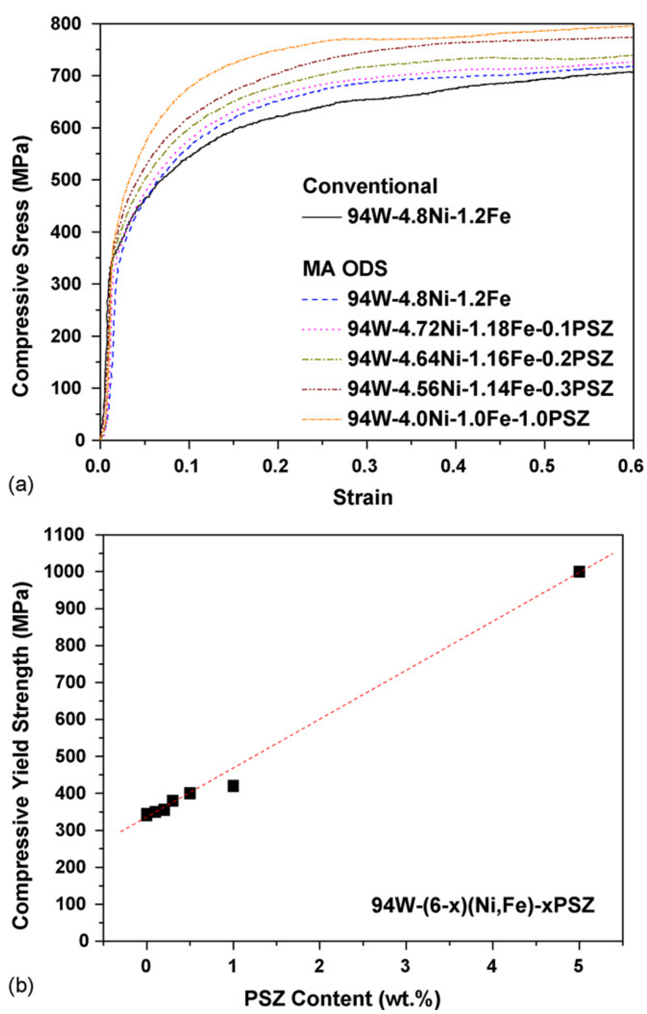

Fig. 4. High temperature compressive behavior of ODS tungsten heavy alloys with varying PSZ content at 800 °C and constant strain-rate of $10^1\ s^{-1}$. (a) Stress–strain curve and (b) compressive yield strength.

4. Summary

ODS tungsten heavy alloys were fabricated by the mechanical alloying and liquid phase sintering process. The location of oxide dispersoids in sintered ODS tungsten heavy alloys can be controlled by controlling the mechanical alloying process. The yield strength of ODS tungsten heavy alloys was not affected by the location of oxide dispersoids. However, elongation of ODS tungsten heavy alloys can be enhanced by control of the location of oxide dispersoids when prepared by modified mechanical alloying processes such as two-step mechanical alloying process or mechanical alloying and mixing process. The high temperature yield strength sensitively increases with increasing the oxide content, which indicates that the oxide dispersoids act as main strengthening agent at high temperature.

Acknowledgement

This work was supported from AOARD and AFOSR through the contract no. 034032.

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