Journal of Nuclear Materials 470 (2016) 236–243

Contents lists available at ScienceDirect

Journal of Nuclear Materials

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

Thermal shock behavior of fine grained W–Y_2O_3 materials fabricated via two different manufacturing technologies

Mingyue Zhao [a], Zhangjian Zhou [a, *], Ming Zhong [b], Jun Tan [a], Youyun Lian [c], Xiang Liu [c]

[a] School of Materials Science and Engineering, University of Science and Technology, Beijing, Beijing 100083, China
[b] Beijing Tian–long Tungsten & Molybdenum Co., Ltd, Beijing, Beijing 100083, China
[c] Southwestern Institute of Physics, P.O. Box 432, Chengdu 610041, Sichuan, China

ARTICLE INFO

Article history:
Received 15 September 2015
Received in revised form
23 November 2015
Accepted 27 December 2015
Available online 30 December 2015

Keywords:
Tungsten alloy
Thermal shock resistance
Thermal conductivity
Mechanical property

ABSTRACT

Thermal shock resistance of fine grained W–Y_2O_3 materials fabricated by two different manufacturing technologies (i.e. spark plasma sintering and high temperature sintering in combination with hot rolling deformation) was examined under transient high heat loads below and slightly above the melting threshold of pure tungsten. The tests were performed with the electron beam test facility EMS–60 at Southwestern Institute of Physics, China. The comparison of the thermal shock response in this work showed that the deformed W–Y_2O_3 performed a superior behavior to spark plasma sintered W–Y_2O_3 in suppressing the crack formation, melting resistance and recrystallization resistance. The thermo–physical properties and mechanical characterizations necessary for understanding the thermal shock response of these materials were also presented and discussed.

1. Introduction

A challenging issue for the development of future fusion devices and reactors will be choosing a suitable plasma–facing material (PFM). Today, due to the high melting point, high thermal conductivity, modest thermal expansion, high elastic modulus, low tritium retention fraction and erosion rate, tungsten (W) has been the first choice as PFM for the highly thermal loaded parts, i.e. the divertor armor [1]. In the future fusion devices and reactors, besides steady–state heat loading of 5–20 MW/m^2, the divertor armor materials will be exposed to transient high heat loads such as edge localized modes (ELMs, in the order of 1 MJ/m^2 for ~0.5 ms) and disruptions (several 10 MJ/m^2 for several ms) [2–4]. During these events high temperature gradients and as a consequence, high thermal stresses will be generated, resulting in the structural or functional failure of the components by the formation of cracks, recrystallization and grain growth, a melt layer and material erosion [5,6]. Therefore, the behavior of W crack formation and melting under transient high thermal loads is among the most important topics to be analyzed.

Recent research found that the thermal shock resistance of materials can be improved by controlling the microstructure (grain size and orientation) through different manufacturing process [7] or by dispersion strengthening with stable high melting point particles, for instance, yttrium oxides (Y_2O_3) [8–10]. In this study, we focus on the fabrication of Y_2O_3 dispersion strengthened tungsten materials via two different manufacturing technologies, and test their behavior of crack formation and melting under electron beam irradiation. In comparison, the ultra–high–purity tungsten (W–UHP) was used as a reference material [11,12]. To gain an insight into the thermal shock behavior (e.g. the cracking patterns and melting resistance), the related thermo–physical (e.g. thermal conductivity) and mechanical properties were tested and compared at room temperature (RT) and elevated temperatures.

2. Material and testing procedure

2.1. Preparing mechanically alloyed W–Y powders

Powders of commercial pure W (with an average particle size of 2.0 μm and a purity of 99.9%) and Y (48 μm, 99.9%) were used as starting materials and mixed together according to the nominal composition of W–1 Y (in wt. %). Then the mixture powders of W and Y were charged into a vessel made of WC/TZM together with

* Corresponding author. Laboratory of Special Ceramics and Powder Metallurgy, School of Materials Science and Engineering, University of Science & Technology Beijing, Beijing 100083, China.
E-mail address: zhouzhj@mater.ustb.edu.cn (Z. Zhou).

http://dx.doi.org/10.1016/j.jnucmat.2015.12.042
0022-3115/

WC/TZM balls for mechanical alloying (MA) in a planetary ball mill for 30 h with a rotate speed of 300 rpm. The inner atmosphere of the vessels for MA was a purified Ar gas (purity 99.99999%).

2.2. Preparing $W–Y_2O_3$ materials via various manufacturing technologies

For the spark plasma sintered $W–Y_2O_3$ alloy, namely, SPSed $W–Y_2O_3$, the mechanically alloyed powders taking out from WC vessel were placed into a graphite tool and subjected to sintering in vacuum. The samples were first held at 1373 K for 2 min and then sintered at 1873 K for 3 min. The applied pressure was 50 MPa. The dimensions of the as–sintered compact were approximately 20 mm in diameter and 3 mm in height. As presented in our previous work [13], the Y elements were totally transformed into Y_2O_3 particles, which are homogeneously distributed along the grain boundaries with a multi-modal size distribution (see Fig. 1a). The center of the peaks in the multi-modal distribution of Y_2O_3 particles is 60 nm, 131 nm and 240 nm, respectively. The tungsten grains exhibits an isotropic microstructure with an average grain size of 0.77 μm. The measured density of the compact tested by Archimedes method is 18.5036 g/cm^3, corresponding to a relative density of 99.30%.

The production route for the bulk deformed $W–Y_2O_3$ alloy consists of four steps: (1) preliminary densification of mechanically alloyed W–Y powders taking out from TZM vessel to square geometry by cold isostatic pressing (2) sintering densification in flowing hydrogen atmosphere at 2573 K for 4 h; (3) one–way rolling for obtaining a plate with a deformation of about 75%; (4) removal of residual stresses by a stress relief treatment at 1373 K to obtain better mechanical properties, e.g., strength and toughness. According to our previous work [14], an isotropic microstructure with an average width of 2.3 μm and an average length of 7 μm were formed as a result of the deformation process, see Fig. 1c. In order to compare the size distribution of Y_2O_3 particles properly, the microstructure of $W–Y_2O_3$ without being subjected to hot rolling, i.e., sintered $W–Y_2O_3$ in flowing H_2, is presented in Fig. 1b. It is observed that the Y_2O_3 particles are located at the grain boundaries with a typical bimodal size distribution, i.e., composing of two portions of particles with particle size of ~0.68 and 1.1–1.7 μm, respectively. After rolling, the large Y_2O_3 particles were reported to show elongated grains while the fine ones preserved

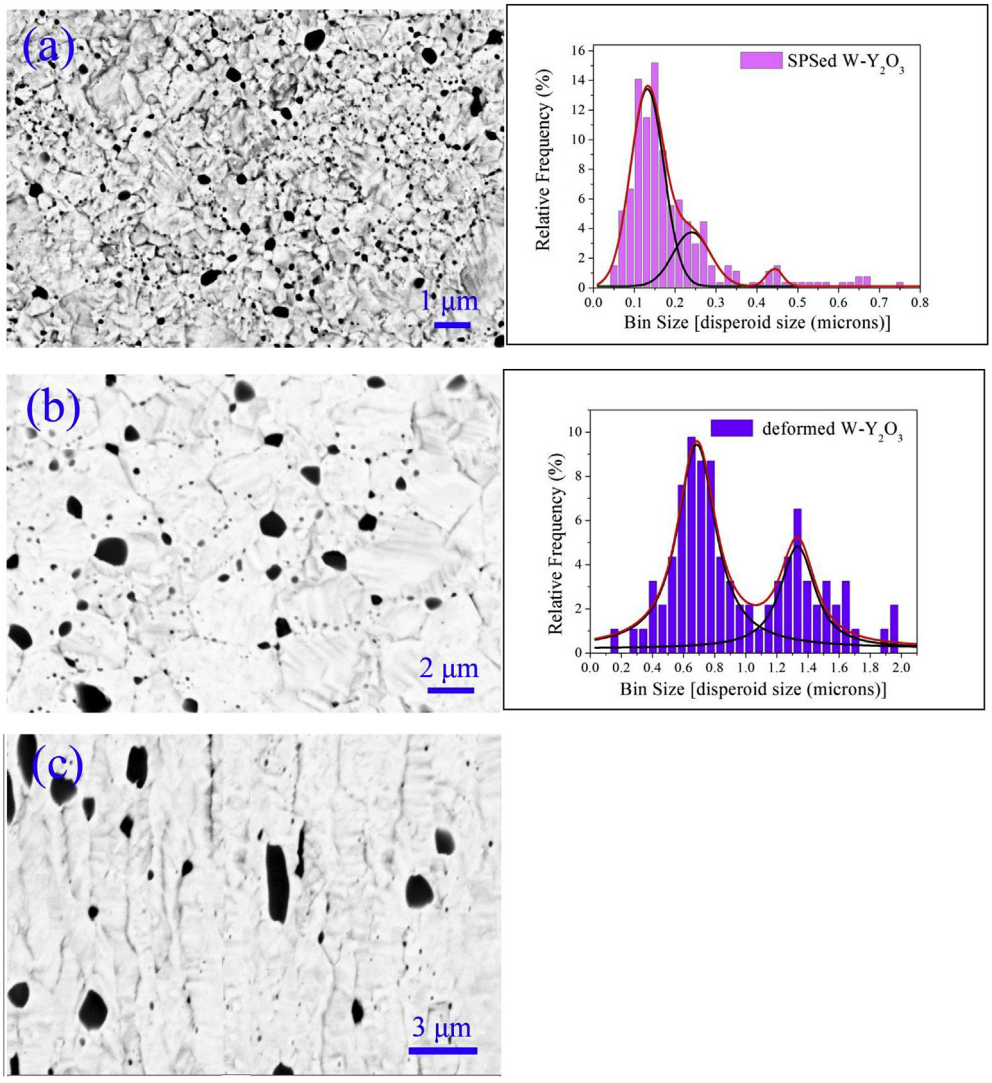

Fig. 1. SEM images and size distribution histograms for visible dark Y_2O_3 particles of SPSed $W–Y_2O_3$ (a), sintered $W–Y_2O_3$ in flowing H_2 (b) and deformed $W–Y_2O_3$ (c). A Gaussian Fit was performed on the histogram. The dark lines are the Gaussian fits for each peak, and the red line is the sum of the black lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)