Powder Technology 269 (2015) 437–442

Contents lists available at ScienceDirect

Powder Technology

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

Development of tungsten as plasma-facing materials by doping tantalum carbide nanoparticles

Xiao-Yue Tan [a], Lai-Ma Luo [a,c,*], Ze-Long Lu [a], Guang-Nan Luo [b], Xiang Zan [a,c], Ji-Gui Cheng [a,c], Yu-Cheng Wu [a,c,*]

[a] School of Materials Science and Engineering, Hefei University of Technology, Hefei 230009, China
[b] Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, China
[c] Engineering Research Center of Powder Metallurgy of Anhui Province, Hefei 230009, China

ARTICLE INFO

Article history:
Received 19 April 2014
Received in revised form 20 August 2014
Accepted 20 September 2014
Available online 8 October 2014

Keywords:
Wet chemical process
Spark plasma sintering
W/TaC alloys
Thermal conductivity

ABSTRACT

Tungsten and its alloys are primary plasma-facing materials in fusion reactors. In this study, pure W and W/TaC alloys and their powders were developed via a powder metallurgical method and a novel wet chemical process, respectively. W alloys with 1, 2, and 4 wt.% TaC were sintered via spark plasma sintering at 1800 °C for 1 min. The sintered samples were characterized using field-emission scanning electron and transmission electron microscopes. TaC particles were found in grain boundaries, which could be crack sources. TaC particles were also found in grain interiors, which changed the crack propagation path, thereby improving material toughness. The microhardness and thermal conductivity of the pure and doped W materials were investigated. The particle microhardnesss increased with the increase in TaC content. The W–1 wt.% TaC alloy exhibited the highest thermal conductivity (up to 183.8 W/mK).

1. Introduction

Tungsten and its alloys are plasma-facing materials (PFM) that were used for the international thermonuclear experimental (ITER) divertor and have been regarded as the most promising plasma materials for future fusion reactors [1–3]. This finding is mainly attributed to the high melting point (3410 °C), high temperature strength, and good thermal conductivity of tungsten and its alloys, particularly its low sputtering yield in radiation environment and its low tritium retention property [4–6]. However, the high ductile-to-brittle transition temperature (DBTT) of pure tungsten and tungsten-based materials is the key barrier during processing and application [7]. The body-centered cubic crystal structure of tungsten has almost no ductility. As such, this metal cannot be used for structural applications at temperatures lower than DBTT. At elevated temperatures, low recrystallization is another factor that decreases the strength and creep resistance of tungsten and its alloys at high temperatures [8,9]. Therefore, second-phase addition has been an effective way to improve ductility by lowering DBTT and by improving recrystallization temperature. Several dispersed oxides such as La_2O_3 and Y_2O_3, and carbides such as TiC, HfC, and ZrC were doped into tungsten-based materials and distributed at the grain boundary or in the grain interior to inhibit recrystallization and grain growth as well as improve the high-temperature strength and creep resistance by hindering grain boundary sliding [10–14]. Moreover, high density grain boundary existing in the nanostructural materials could function as a place of annihilation for radiation-induced defects, thereby resulting in the improved irradiation resistance of materials [15]. Nanostructured-doped second-phase tungsten alloys are potential solutions to these problems.

Up to date, most nanostructured tungsten alloys doped with second-phase materials are prepared via mechanical milling [16,17]. However, some harmful elements from balls, containers, or milling media are introduced into the alloys through this method. These elements affect material properties. In addition, resulting powders sometimes adapt to

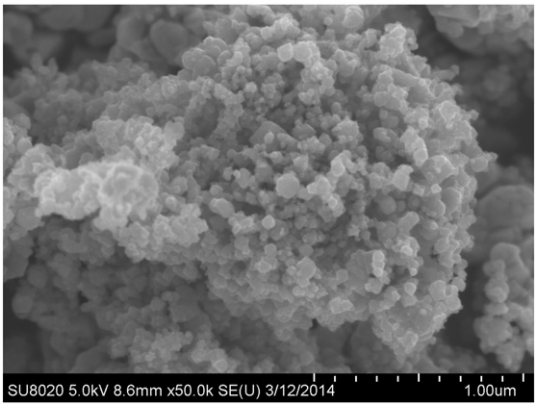

Fig. 1. FESEM image of the doping TaC powder.

* Corresponding authors at: School of Materials Science and Engineering, Hefei University of Technology, Hefei 230009, China. Tel./fax: +86 551 62901012.
E-mail address: luolaima@126.com (L.-M. Luo).

http://dx.doi.org/10.1016/j.powtec.2014.09.039
0032-5910/

Table 1
Content of added chemicals.

	Pure W	W–1TaC	W–2TaC	W–4TaC
APT (g)	34.6787	34.3321	33.9853	33.2917
TaC (g)	0	0.2500	0.5000	1.0000

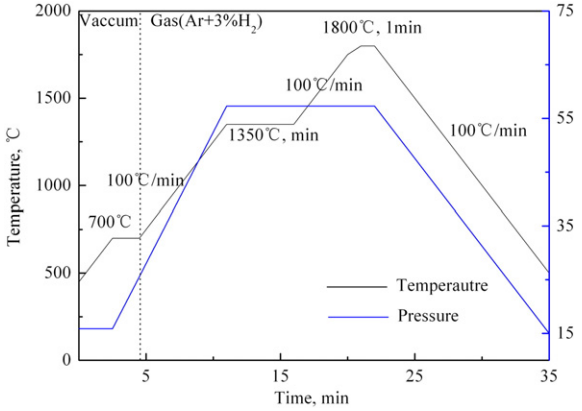

Fig. 2. Temperature and pressure profile of SPS process of the W and W/TaC alloys.

high internal stresses caused by large deformation during milling; thus, samples easily crack during sintering [18,19]. To solve these problems, a wet chemical process is introduced to produce high-purity nanocomposites. This method is suitable for fabricating W-based composites with uniform distribution of second-phase materials. In this study, different contents of tantalum carbide (TaC) nanoparticles doped in tungsten powders were synthesized via the proposed wet chemical process. However, preparing the bulk W from nanoparticles and preserving the nanosized structure are difficult to accomplish using this method. Such difficulties are attributed to the presence and rapid growth of nanosized particles that possess numerous exposed surfaces; thus, high surface energy was decreased at high temperatures.

To control the nanosized composite powder, spark plasma sintering (SPS) technology has been applied in sintering bulk materials. The obtained powder was placed into an electrically and thermally conductive graphite die, and a DC current is then applied in pulses to allow the synthesis of samples at fast heating and cooling rates. A uniaxial high mechanical pressure can be assisted during the process and can facilitate the densification of sintered materials. SPS uses direct current heating and high mechanical pressure that can produce fine grain and high-density powder materials at relatively low temperatures [20–22].

In the current study, TaC nanoparticles were doped into tungsten powder via wet chemistry methods, and the obtained W/TaC composite powders were consolidated via SPS. The doped powders were investigated via different methods before and after sintering.

2. Experimental

2.1. Synthesis of W/TaC composite powder

The TaC contents of the doped W precursor (W–1.0 wt.% TaC, W–2.0 wt.% TaC, and W–4.0 wt.% TaC) were determined by stoichiometry. The precursors were synthesized from ammonium paratungstate $(NH4)_{10}H_2W_{12}O_{42}\cdot 4H_2O$ (APT) and TaC particles with a particle size of approximately 50 nm (Fig. 1). A small amount of TaC nanoparticles were doped in an aqueous solution of oxalic acid, and a suspension solution was obtained via ultrasound-assisted dispersion. The ultrasonic equipment was turned off after the APT powder was dissolved in the suspension solution and the TaC nanoparticles were uniformly dispersed in the solution. Table 1 shows the different TaC contents that

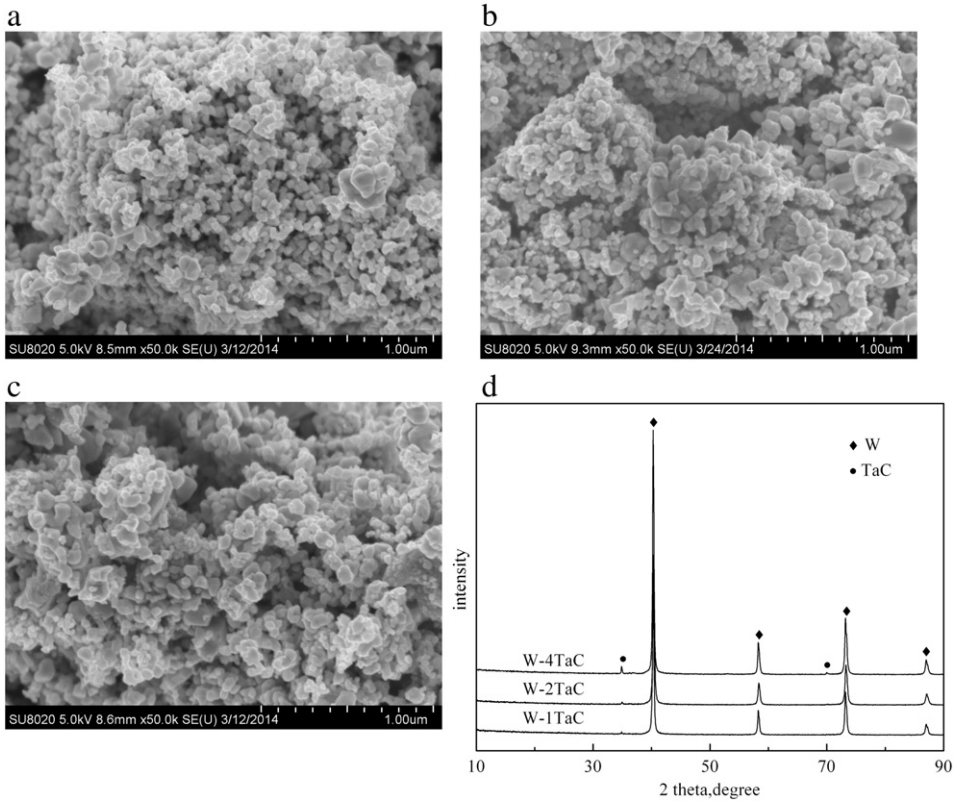

Fig. 3. FESEM images and XRD pattern of W/TaC composite powder. (a) W–1 wt.% TaC; (b) W–2 wt.% TaC; (c) W–4 wt.% TaC; (d) XRD pattern of W/TaC with different contents of TaC.