Int. Journal of Refractory Metals and Hard Materials 59 (2016) 105–113

Contents lists available at ScienceDirect

Int. Journal of Refractory Metals and Hard Materials

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

Fabrication of homogeneous tungsten porous matrix using spherical tungsten powders prepared by thermal plasma spheroidization process

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ARTICLE INFO

Article history:
Received 14 March 2016
Received in revised form 29 May 2016
Accepted 4 June 2016
Available online 7 June 2016

Keywords:
Spherical tungsten
plasma spheroidization
Uniform pore
Porous matrix
Kinetic analysis

ABSTRACT

In this work, spherical and dense tungsten particles with average size of 13 μm were synthesized by thermal plasma spheroidization process, and were further used to fabricate porous tungsten matrix with homogeneous pore distribution and open pore channel. The influences of sintering temperatures, dwelling time and additive on the microstructure and microhardness evolution of porous products were investigated, and the experimental results show that spherical and dense particles could keep their initial shape and favor the reservation of packed pores with narrow pore size distribution, which exhibits superiority in fabrication of tungsten matrix with uniform pore distribution compared with irregular tungsten powders. Specially, the porosity of porous tungsten matrix could be finely tuned from 25% to 30%, which has obvious effect on microhardness of obtained porous skeleton. The sintering kinetic analysis indicates that grain boundary diffusion is the primary mass transport mechanism during the fabricating porous tungsten matrix process. Furthermore, W—Cu composites fabricated by spherical powders exhibit higher thermal conductivity than that of irregular powders, which reveals the superiority of spherical tungsten powder.

1. Introduction

Tungsten in its porous form has been widely used as a matrix in mechanical, electrical engineering and high temperature applications owe to its brilliant characteristics such as high hardness, hot strength, wear resistance, and high melting point [1]. Typically, partially sintered (~<80% of theoretical density) tungsten is further served as the matrix impregnated with metals (such as Cu/Ag) and alkaline earth oxides and applied in electrical contact field and high current density cathode [2–7]. In these applications, porous tungsten matrix with homogeneous pore distribution and high open porosity are two key factors to obtain uniform infiltrates distribution, which has a significant influence on the performance of targeted materials. For example, a uniform and interpenetrated open porosity tungsten skeleton is a significant point to obtain homogeneous organizational structure of W—Cu composites, which is critical for realization of high electrical conductivity [8–10]. In addition, to manufacture dispenser cathode, homogeneous pore distribution and open pore channel of the tungsten matrix are essential for uniformly distributed and supplied in time of the emissive material [2,3,11], which favors the realization of continuous and steady electrons emission. Moreover, The addition of small amounts of some transition metals such as nickel could lower the activation energy of sintering, which make it possible to reduce the sintering temperature of tungsten significantly [12,13]. Therefore, fabrication of porous tungsten matrix with homogeneous and interpenetrated open porosity is crucially important to further obtain outstanding properties materials.

Up to now, most of researches on fabrication of porous tungsten matrix focus on irregular tungsten particles, which suffers the drawbacks such as uneven pore distribution and negative effect on void holding, and further deteriorate the mechanical properties of porous materials. For example, tungsten skeleton prepared by polygonal tungsten particles manifested uneven pore distribution of sintered porous compacts and affected the uniformly infiltrated of copper [14], which may worsen the electrical conductivity of materials used in electrical contact field. Further investigations showed that non-uniform pore distribution formed by irregular particles may degrade the mechanical properties of porous matrix due to the uneven shrinkage of sintered compacts [15,16]. Compared to irregular powders, spherical particles with high density have shown its superiority for fabrication of porous skeleton with homogeneous pore distribution. For example, porous silica ceramics with uniform and fully interconnected pores could be obtained by sintering of spherical SiO_2 particles, and the results indicated that the packed pores were well reserved and uneven shrinkage was restrained effectively [17]. Specially, spherical and densely internal particles allow regular packing, which facilitates the formation contiguous and interlinked pores formed by neighbored particles [18] and inhibits the closed pore development. However, spherical tungsten particles

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http://dx.doi.org/10.1016/j.ijrmhm.2016.06.002
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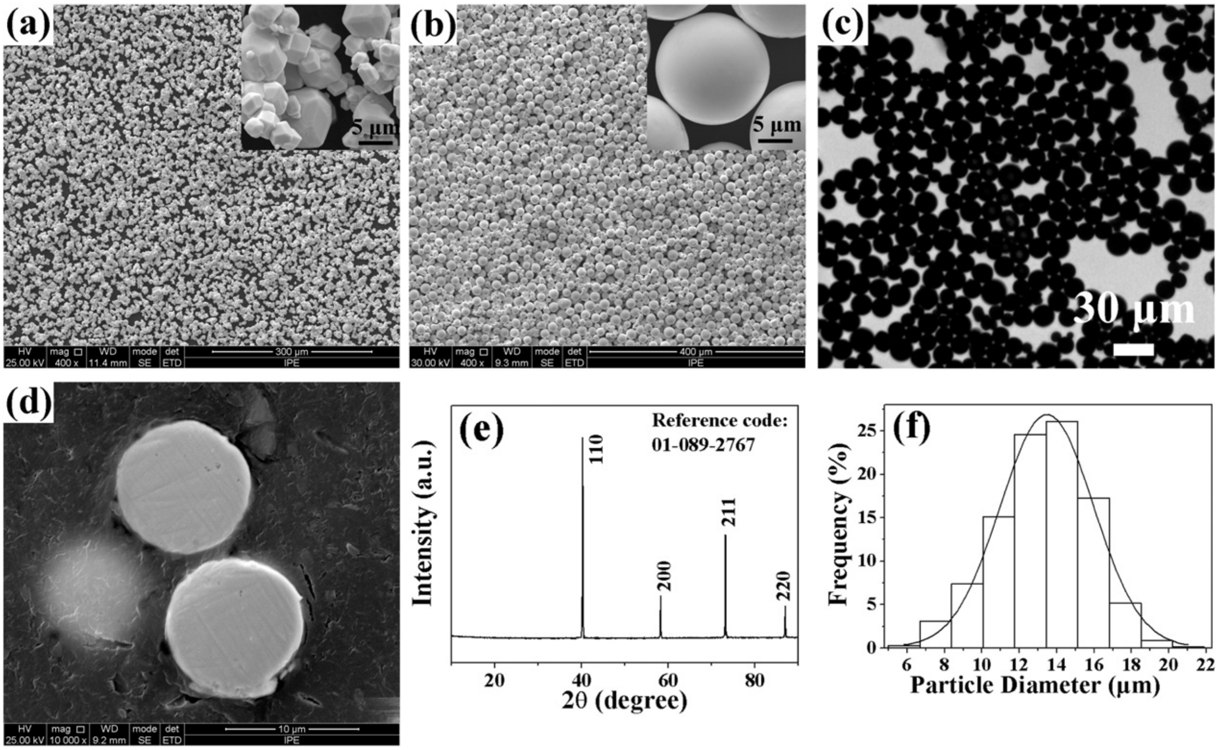

Fig. 1. (a) SEM of irregular tungsten powders and (b) SEM, (c) optical micrographs, (d) cross-section image, (e) XRD pattern, (f) particle size distribution of spherical tungsten powders produced by RF thermal plasma route.

with high density are hard to be synthesized due to their high melting temperature and few studies focused on manufacture porous tungsten matrix using spherical tungsten powders were reported. The sintering process and related mechanism of spherical tungsten powders are also seldom involved.

In this work, spherical and dense tungsten particles with homogeneous size distribution was produced by Radio-Frequency (RF) induction thermal plasma spheroidization process, which were further applied to fabricate porous tungsten matrix. The fabrication process of porous tungsten matrix was systematically analyzed under different conditions. Experimental results reveal that particles with spherical shape and densely internal structure favor the reservation of initial shape and packed interpace during sintering process, and uniform pore with interpenetrated channels was obtained. Specially, the porosity of porous compacts with 25–30% could be finely tuned by controlling the experimental parameters. Furthermore, kinetic analysis indicated that the grain boundary diffusion is the dominant mechanism during the sintering process, and high activated energy compare to irregular particles is beneficial to the reservation of initial shape and packed interpace. In addition, infiltration experiments were carried out to fabricate W—Cu composites, which further proved that the porous skeleton fabricated by spherical powders possess superiority on thermal properties of W—Cu composites.

2. Experimental

2.1. Spherical tungsten prepared by plasma-spheroidization process

Spherical tungsten powders used in this study were produced by Radio-Frequency induction thermal plasma and specific

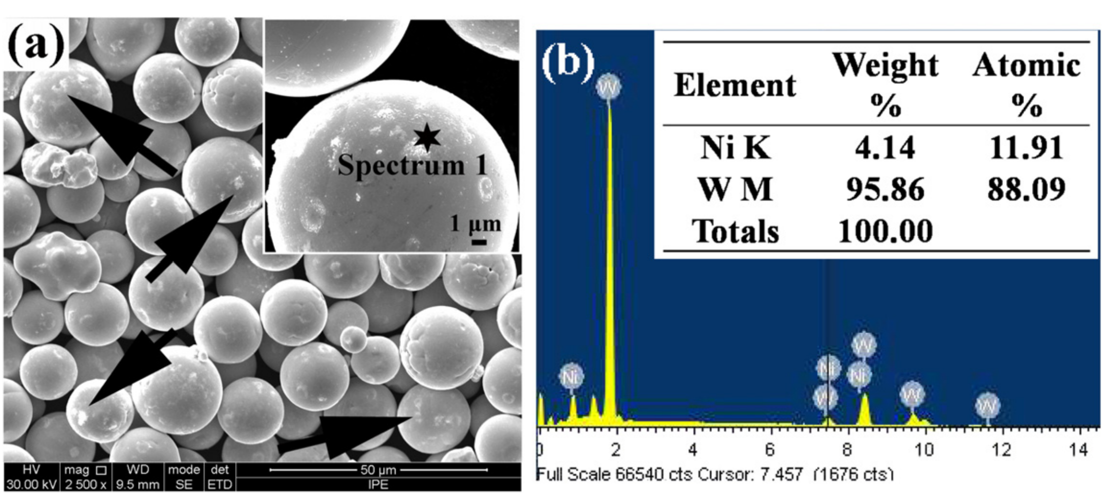

Fig. 2. SEM image and EDS analysis of W spheres loaded with 0.03 wt.% nickel.