SPECIAL FEATURE

Metal injection molding of tungsten and its alloys

Wei Wang*, **Jiupeng Song, Binyou Yan and Yang Yu**

China National R&D Center for Tungsten Technology, Xiamen Tungsten Co. Ltd., Anling Road 1005, Xiamen 361021, China

Metal injection molding (MIM) process of tungsten (W) and its alloys is investigated, including W, oxide dispersion strengthened (ODS) W, tungsten–copper (W–Cu) and tungsten heavy alloy (WHA). The ultrafine powder fabrication technology for W, ODS-W and W–Cu composite are presented, which is important for achieving the high sintered density and homogeneous microstructures. W powder developed with high flowability has been applied for MIM WHA. Wax-based binders have been employed for the feedstock fabrication, respectively. Some applications of the above materials are shown in this paper.

Introduction

The physical properties of tungsten such as the high melting point, high density, high strength and thermal conductivity, the low thermal expansion and low erosion rate make this material and its alloy widely used in many industries such as defense and military, aerospace, nuclear industry, and electronic industry. However, the application of tungsten and its alloy are limited due to the difficulty in densification and machining. Metal injection molding technology (MIM) is a combination of plastic injection molding and powder metallurgy, which endows metal powder higher flowability by adding polymer binder. This process enables the mass production of low cost, high performance components with complex geometries. Materials with high melting points such as tungsten or tungsten alloys could be effectively fabricated with this process. With the proper powder deagglomeration and binder system, a few number of tungsten-based MIM part has been successfully developed.

MIM examples with ultrafine powder

Pure tungsten cathodes for ion implanter

Tungsten cathode is a consumable part in ion implanters, which is widely applied in semiconductor device fabrication. Traditionally wrought tungsten rods are machined to make the cathodes, with about 80% material being removed due to their complex geometry. MIM process can be a cost-effective alternative for manufacturing the cathode by net-shaping forming method.

A type of deaggolomerated W powder was used in the experiments. The Fisher Sub Sieve Sizer (FSSS) particle size was 0.7 μm (Fig. 1). A wax-polymer binder system was selected for MIM feedstock. The binder contains 51 w/o paraffin wax (PW), 30 w/o polypropylene (PP), 16 w/o polyethylene (PE) and 3 w/o stearic acid (SA). The feedstock with the solid loading of 51 v/o was injected on a molding machine. Solvent debinding was carried out in heptane at 37°C for 120 min. The thermal debinding and sintering procedure were undertaking in pure hydrogen atmosphere. The peak temperature of sintering process is 1900°C for 2 h. The image of injection molded and sintered W cathode is shown in Fig. 2.

The sintered density of W cathode is 18.95 g/cm^3, which already reach a relative density of 98.4%. The microstructure observed by light optical microscope (LOM) (Fig. 3) shows that the grain size is 15–20 μm. Using the submicron W powder in this study improved the sinterability at the expense of solid loading of the feedstock. Zeep et al. [1,2] used the W powder with FSSS particle size approximate 2 μm, and the solid loading can reach 55 v/o. The sintering temperature was higher than 2000°C, but the sintered part showed a relative density of 96%, the grain size of 18 μm, and the hardness 360 HV10.

In order to improve the final density of pure W MIM parts, hot isostatic pressing (HIP) is often employed. MIM W parts are first sintered to achieve a closed porosity state for the following HIP

*Corresponding author. Wang, W. (chemww7@gmail.com)

0026-0657/ http://dx.doi.org/10.1016/j.mprp.2016.10.066

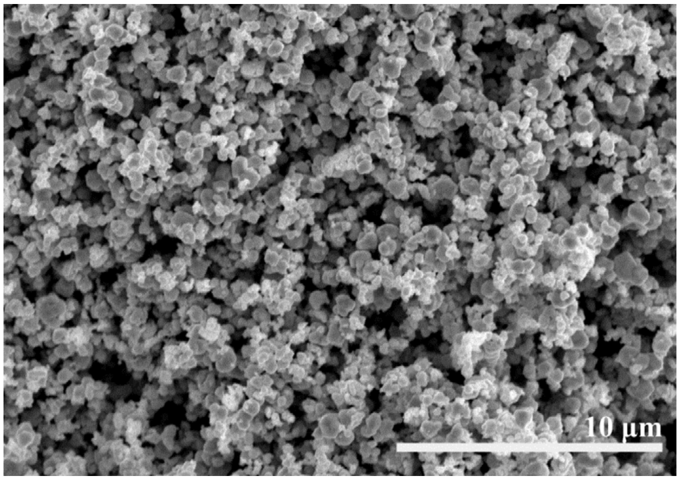

FIGURE 1

SEM images of deaggolomerated W powders used in the experiments with particle size FSSS 0.7 μm.

treatment, as summarized in Table 1. The final density, hardness and microstructure of the sintered W IHC obtained by using submicron W powder and high temperature sintering in this study is similar to the others with HIP treatment.

FIGURE 2

Injection molded and sintered W cathode.

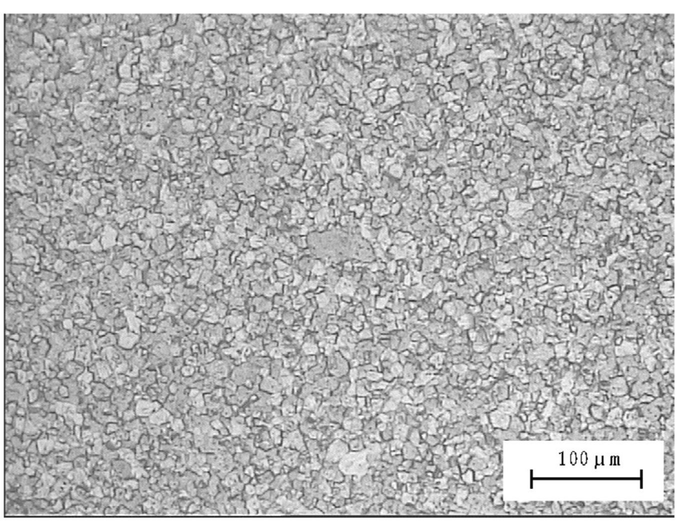

FIGURE 3

LOM image of the sintered IHC.

TABLE 1

Comparison of various processes and properties of MIM W.

	This study	References [1,2]	Reference [3]	Reference [4]
W powder	FSSS 0.7 μm	FSSS 0.7 μm	50% FSSS 0.7 μm + 50% FSSS 1.7 μm	FSSS 1–2 μm
Sintering process	1900°C, 2 hours	1650°C, 2 hours	1800°C, 2 hours	>2000°C
HIP treatment	No	1500°C, 280 MPa, 2 hours	2100°C, 250 MPa, 3 hours	1500°C, >300 MPa
Sintered density	98.4%	98%	98.6–99%	97.4–98%
Hardness	433 HV0.1 387 HV10	/	457 HV0.1	354–363 HV10
Grain size	Several μm	5.5 μm	3–7 μm	Several μm

ODS-W MIM parts for fusion devices

Oxide dispersion strengthened tungsten (ODS-W) components with complex shapes will be used in Langmuir probes in ITER and He-cooled diverter in future fusion devices [5]. Due to the harsh environment, high density and fine grain size is most important requirement for choosing material, so MIM process with ultrafine ODS-W powder is an attractive method for fabricating fusion devices.

The ODS-W powder is acquired by liquid phase doping method. The basic properties of this powder are listed in Table 2.

The mixing, injection molding and debinding process of ODS-W are similar to the pure tungsten. The sinter temperature is 1850°C for 2 hours, which is lower than pure tungsten. The sintered density of ODS-W material is 18.41 g/cm^3, which already higher than the relative density of 99%. The scanning electron microscope (SEM) in Fig. 4 shows that the grain size is 3–5 μm. The higher sinter density and fine grain size is attributed to the lower sinter temperature and grain refinement effect of Y element. The mechanical properties and thermal shock tests of ODS-W material is still in progress.

W–Cu shaped charge liners in oil penetration

Shaped charges are widely used for perforations in the field of oil and gas production. Tungsten–copper (W–Cu) is an attractive material for shaped charge liner due to the combination of the high density of W and the good plasticity of Cu [6]. It is difficult to fabricate the W–Cu pseudo-alloy with a very homogeneous microstructure by using conventional Cu infiltration or mixed powder, which is important for the shaped charged liner to form a stable metal jet during explosion.

To solve this problem, a type of submicron W–Cu composite powder [7] (Fig. 5) has been developed by thermo-chemical process. The chemical contents and physical properties of the ultrafine W–Cu composite powder were listed in Tables 3 and 4.

TABLE 2

Basic properties of ODS-W powder.

Y_2O_3 content (wt.%)	0.95	FSSS particle size (μm)	0.73
N content (ppm)	120	D10 (μm)	0.81
O content (ppm)	3189	D50 (μm)	3.66
Apparent density (g/cm^3)	1.8	D90 (μm)	7.83

Please cite this article in press as: W. Wang, et al., Met. Powder Rep. (2016), http://dx.doi.org/10.1016/j.mprp.2016.10.066