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Properties of Ultrafine-Grained Tungsten Prepared by Ball Milling and Spark Plasma Sintering

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Abstract: This work studies preparation and properties of fine-grained tungsten which is thought to be more resistant to the harsh conditions inside a nuclear fusion device than standard coarse-grained tungsten. Three types of tungsten were prepared, two of them from ultrafine-grained tungsten prepared in a planetary ball mill. Flexural strength, microhardness and thermal conductivity are studied. In this paper, preliminary results are introduced.

Introduction

Tungsten is currently considered as a most suitable plasma facing material for nuclear fusion reactor. The so-called first wall will be subjected to harsh conditions that will gradually deteriorate properties of the wall material. For example, irradiation by neutrons and ions and subsequent forming of He bubbles in the material cause a substantial degradation of mechanical and thermal properties [1]. Some studies point out that fine-grained tungsten could be more resistant to radiation than coarse-grained tungsten [2]. Tailoring of tungsten microstructure is very laborious. Due to its high melting point, tungsten is very often processed mechanically and subsequently sintered into a compact body.

In this study, preparation of ultrafine-grained tungsten by mechanical processing in a planetary ball mill was examined. Three types of tungsten were compared. One was made from micron-size tungsten powder consolidated by spark plasma sintering (SPS). Other two samples (pure tungsten and tungsten with addition of Y_2O_3) were prepared from the powder processed in a planetary ball mill. After ball milling the powders were consolidated by SPS, i.e. fast sintering process that allows preserving fine-grained structure of the powder material. Properties of the samples such as microhardness and thermal conductivity were examined and correlated with the grain size.

Experimental

The ultrafine-grained tungsten was prepared using planetary ball mill PULVERISETTE 5 (FRITSCH GmbH, Germany) from a tungsten powder with initial average size of particles of 2 microns. The milling was performed in a tungsten carbide vial with tungsten carbide balls under argon atmosphere. Milling velocity was 240 rpm and the total milling time 25 h.

Powders were consolidated by SPS 10-4 (Thermal Technology, USA) under 1800 °C, 70 MPa and hold time of 2 min. The samples prepared from the milled powder are referred as W_M (tungsten only) and W_{MY} (tungsten with addition of Y_2O_3). Samples prepared from the initial powder are referred as W_0 and serve as reference for properties of W_M and W_{MY} samples.

Thermal diffusivity was measured by the xenon-flash method using Anter FL-3000 (Anter, Pittsburgh, PA, USA) under a nitrogen atmosphere.

Results and discussion

Ball milling under specified conditions led to a significant decrease of particle size of the initial powder, i.e. from median value around 1,2 micron prior milling (number distribution of the particle sizes in the measured powder) to median value around 250 nm after milling. The crystallite size determined by X-ray diffraction of the milled powder batches was less than 15 nm and remained within hundreds of nanometers after sintering into compact bodies.

Microstructure of the prepared samples is presented in Fig. 1. Fine grains surrounded by Y_2O_3 particles (dark spots) are fairly visible in the case of W_{MY} sample.

The influence of powder processing as well as the yttria particle reinforcement on hardness of the prepared materials is quite significant (Fig.2). More important are the results of thermal conductivity where a major increase for the W_M sample was observed (Fig.3).

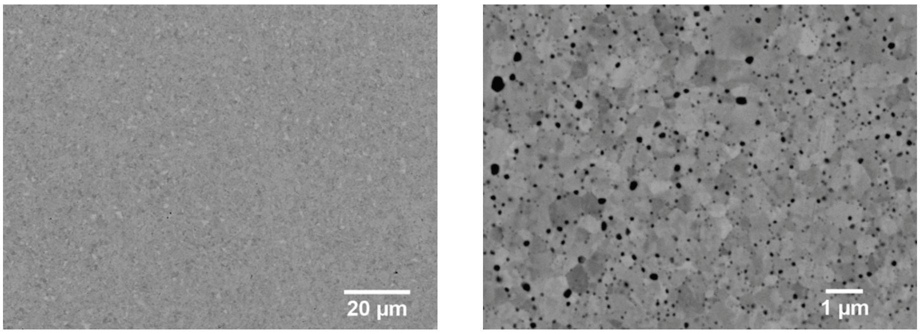

Fig. 1: Microstructure of W_M (left) and W_{MY} (right) sample

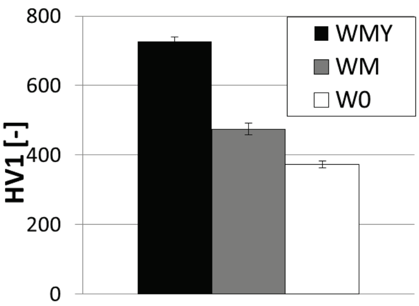

Fig. 2: Hardness of the tungsten samples

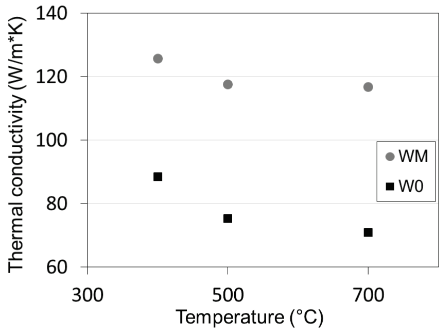

Fig. 3: Thermal conductivity of the tungsten samples

Conclusion

Powder processing in a planetary ball mill has a significant effect on the properties of prepared tungsten samples. Especially increase in the thermal conductivity will have a positive effect on the behavior under fusion like condition.

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