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Effects of vanadium concentration on the densification, microstructures and mechanical properties of tungsten vanadium alloys

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ABSTRACT

Tungsten based vanadium alloys have been fabricated by powder metallurgy and consolidated by spark plasma sintering (SPS) at temperature of 1600 °C for 3–5 min at 50 MPa. Four different concentrations of vanadium ranging from 1 to 10 wt.% were used to investigate the behavior of the developed alloys. X-ray diffraction analyses were performed for all four compositions of tungsten vanadium alloys. The morphology of cross sectional crack surfaces of sintered alloys was analyzed by scanning electron microscopy. The variations of vanadium concentration has not only shown an obvious impact on the microstructures, but also improved the densification and mechanical properties of the tungsten based materials. The maximum relative density of 98.5% was achieved for the highest concentration (10 wt.%) of vanadium alloy with micro hardness of 507 HV and good bending strength of 692.5 MPa.

1. Introduction

The enormous power density associated with fusion reactor, makes it as a potential candidate for producing the environmental clean and safe energy for the future needs. The damaging effects of high heat flux (HHF) and intense irradiation released by long term operation of a fusion reactor are the concerns of wall materials durability [1]. Tungsten due to its promising properties at higher temperatures is seemed to be a good material for the fusion reactor walls [2–4]. But its durability in such environment is doubtful for long term plasma operation [5–7]. Neutrons and H/He plasma irradiation can result the changes of its surface morphology and strength against HHF and irradiation [8–11]. To troubleshoot the problem of wall materials to survive in such harsh environment for long term operation of plasma, it requires the development of tungsten materials. Attempts have been made to build a data base to develop and study high strength tungsten based alloys for the plasma facing materials (PFMs) [12,13]. Due to the unique capability of vanadium to bear intense neutron irradiation, vanadium alloys are considered as very good structural material for the nuclear reactors [14]. Simulation shows that the addition of vanadium in tungsten improves the mechanical properties and reduces the irradiation damages [15,16]. However, it requires a strong support of experimental work to verify this theory. For fusion reactor application some attempts have been made for the development of W-2V and W-4V alloys by hot isostatic pressing (HIP) technique [17,18]. The production of W-V alloys on massive scale requires commercial sintering process like HIP, but for preliminary investigation SPS is most efficient and low energy consumption process to produce small samples for research and development. HIP is not only complicated and energy consuming process for fabrication of small scale of samples, but also promotes the unwanted grain growth of tungsten [19]. Besides that, effects of a broad range of vanadium concentration on morphology, densification and mechanical properties of tungsten based alloys have also not been reported. Fabrication technique plays an important role in the tungsten grain growth and influences the mechanical properties of tungsten based alloys. SPS is considered as an excellent sintering process which does not allow growth of tungsten grains [20]. The main advantages of adding vanadium is to improve the relative density and suppress the irradiation embrittlement of tungsten as the high porosity acts as strong sinks for H/He bubbles and activated points for defects induced by neutron irradiation.

The detail study of densification, morphology and mechanical properties of tungsten based vanadium alloys with various vanadium compositions, consolidated by SPS is presented here. The aim of this work is to develop and support the industrial

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Table 1
Characteristics of tungsten vanadium alloy samples with different vanadium contents sintered by SPS.

Samples identity	Vanadium concentration (wt.%)	Dwell time at 1600 °C (min)	Theoretical density (g/cc)	Relative density (%)	Tungsten average grain size (μm)	Micro hardness (HV)	Bending strength (MPa)
1V3	1	3	18.84	91.8	3	360.3	541.9
5V3	5	3	17.38	94.5	2	468.4	560.5
7V3	7	3	16.73	96.8	1	507.5	642.4
10V3	10	3	15.84	98.5	2	507	692.5
5V5	5	5	17.38	96.6	2	432	633

production of high strength tungsten based alloy for plasma facing materials' applications.

2. Experimental

99.9% pure tungsten and vanadium powders of 2 μm and 48 μm respective sizes were used for mechanical alloying (MA) process in this investigation. Both kinds of powders were purchased from Beijing Xing Rong Yuan Technology Co., Ltd. The comparatively large size of vanadium was selected because it has good stability against oxidation. High energy ball miller (HEBM) process was used for mixing four different combinations of tungsten vanadium alloys. The alloy powders of four different vanadium concentrations (1 wt.%, 5 wt.%, 7 wt.% and 10 wt.%) were loaded in tungsten carbide ball miller in the argon atmosphere and mixed for 30 h with 4:1 ball to powder ratio at a speed of 380 rpm. The alloy powders were then extracted from the ball miller chambers in the inert environment of glove box. The contents of oxygen and carbon due to clean inert environment was found 0.45 and 0.016 wt.% respectively. The extracted powder was then sealed in graphite die and consolidated in SPS process at temperature 1600 °C for 3–5 min with 50 MPa pressure and the heating rate was 100 °C/min. An about Ø20 × 3 mm^2 targets with a thick micron level carbon and tungsten carbide layers were obtained after consolidation. The unwanted layers from each specimen surface were removed mechanically with emery papers down from 120 to 4000 grad. The density of each sample was measured by Archimedes' principle. The Vickers micro- hardness of the polished surface was determined with a load of 200 g for 10 s as the average of multiple measurements. A well polished 18 mm long bar of 2 × 3 mm^2 cross section specimen of each alloy was subjected for bending test analysis at room temperature. X-ray diffraction (XRD) technique

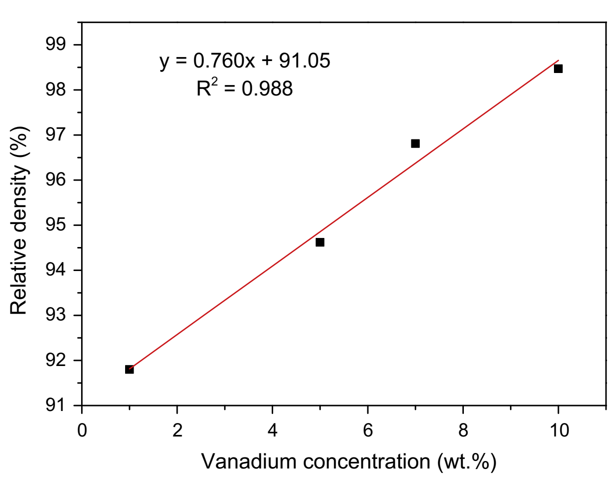

Fig. 1. Influence of vanadium concentration on the relative density of the sintered alloys.

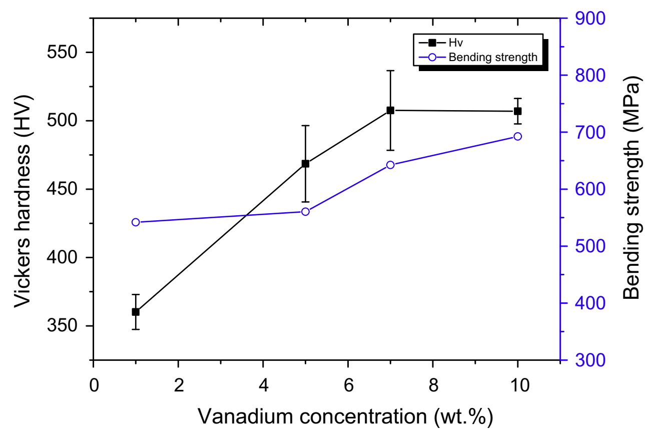

Fig. 2. Plot of micro-hardness and bending strength against vanadium concentration of each tungsten vanadium alloy sample.

was used to analyze the MA behavior of the different vanadium concentration sintered alloy samples. The samples were characterized for microstructure, grain size and multiple phases by scanning electron microscopy (SEM).

3. Results and discussions

The effects of vanadium content (1–10 wt.%) on the microstructure and densification of tungsten vanadium alloys is studied. First four samples (1V3, 5V3, 7V3 and 10V3) are consolidated at 1600 °C for 3 min while the fifth sample (5V5) is sintered at 1600 °C for 5 min under the same pressure conditions of 50 MPa by SPS. The detailed characteristics of the sintered tungsten vanadium alloys, including sintering conditions, densities, average grain size of tungsten and other mechanical properties are summarized in Table 1.

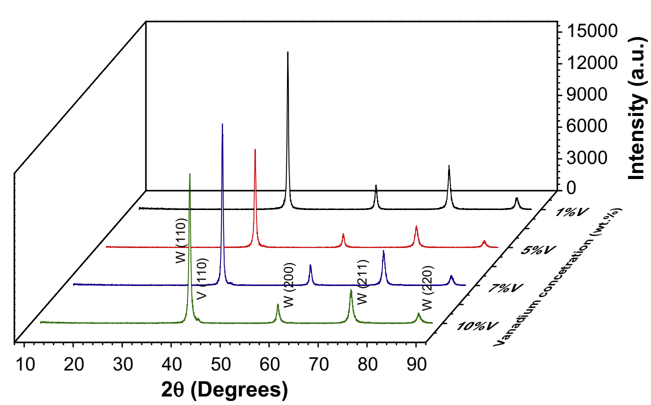

Fig. 3. XRD patterns of tungsten vanadium alloy of different vanadium concentrations.