THERMAL AND MECHANICAL PROPERTIES OF TUNGSTEN COMPACTS PREPARED BY SPS

B. Nevrlá [1] , M. Vilémová [2] , J. Matějíček [3]

Summary: *Tungsten is a promising candidate material for use in the tokamak device aimed at future production of nuclear fusion power. Here, tungsten is intended for the application in the part called first wall, with the function of a heat-resistant plasma facing armor. In the present work, two fractions of tungsten powder (2 and $4\,\mu\mathrm{m}$) were used to prepare two consolidated samples by spark plasma sintering (SPS), using a combination of pressure, temperature and electric power. This sintering technique produces samples of near theoretical density which is positive for the application. Tungsten compacts were then studied to determine some basic thermal and mechanical properties, namely thermal conductivity using the laser-flash method and hardness by Vickers test. The measurements were focused on thermal conductivity of the compacts because high thermal conductivity is crucial for the material of tokamak first wall, loaded by high heat flux from the plasma. High hardness is desirable for good resistance to mechanical erosion. The obtained results pointed out the differences between the two tungsten compacts and provided an idea about suitable production parameters.*

Keywords: *spark plasma sintering, tungsten, thermal properties*

1 Introduction

Tungsten is considered as one of the most promising candidates for plasma facing materials for components in future fusion reactors, such as International Thermonuclear Experimental Reactor (ITER), which will experience severe conditions during operating. Plasma facing components have to resist thermal shocks, surface erosion and very high heat load [1, 2, 3, 4].

Due to its high melting point ($3370\,^\circ\mathrm{C}$), fabrication of tungsten components is very difficult (especially through casting and melting). Most commonly, tungsten is fabricated by the means of powder metallurgy, i.e. shaping a powder into a compact material under applied load and heat [5]. One of the very promising methods belonging to the family of powder metallurgy is so called Spark Plasma Sintering (SPS) sometimes designated as FAST (Field Assisted Sintering Technique). This method uses pressure, electrical current and heat to compact and sinter the powder. The main advantage of this method is short processing time and thus it is frequently used for preserving nanostructure of sintered powder [4]. Moreover, fast sintering leads to reduction of the fabrication costs.

Another promising way for fabrication of tungsten components is deposition of tungsten in the form of a coating on a base material, e.g. by physical vapor deposition or by plasma spraying. In the latter, the coating is built up from flattened powder particles that were melted and accelerated by the spraying device

[1]Mgr. Barbara Nevrlá, Institute of Plasma Physics AS CR, v.v.i., Za Slovankou 1782/3, 182 00 Prague 8, email: nevrla@ipp.cas.cz

[2]Ing. Monika Vilémová, Ph.D., Institute of Plasma Physics AS CR, v.v.i., Za Slovankou 1782/3, 182 00 Prague 8, email: vilemova@ipp.cas.cz

[3]Ing. Jiří Matějíček, Ph.D., Institute of Plasma Physics AS CR, v.v.i., Za Slovankou 1782/3, 182 00 Prague 8, email: matejicek@ipp.cas.cz

towards the base material. As a result of this process, coating structure is layered and inhomogeneous. Such a structure gives the coating specific properties that are in many applications favorable (i.e. heat resistance, strain tolerance) [6].

In the present study, tungsten compacts were fabricated by SPS and their thermal diffusivity, conductivity and hardness were measured. The effect of different grain size of the initial powder was examined for better understanding of the SPS process, with the perspective of tailoring future materials for tokamaks.

2 Experimental

Two samples were prepared by SPS 10-4 (Thermal Technology, USA) from tungsten powders of average grain size of 2 and $4\,\mu\mathrm{m}$ (Osram, CZ), henceforth labeled W2 and W4, respectively. The sintering parameters were the following: the maximum sintering temperature of $1800\,^{\circ}\mathrm{C}$ for 5 minutes, pressure of $60\,\mathrm{MPa}$, protective atmosphere of argon and heating rate of $150\,^{\circ}\mathrm{C/min}$. The samples were about $2.2\,\mathrm{mm}$ thick.

The microstructure was evaluated on polished cross-sections using SEM EVO MA 15 (Carl Zeiss SMT, D) in a backscattered mode.

Porosity was measured using Archimedean method.

Thermal diffusivity was measured at 100, 400, 500, 700 and $900\,^{\circ}\mathrm{C}$ by the laser-flash method using Anter FL-3000 machine (Anter, Pittsburgh, PA, USA) under a nitrogen atmosphere. The bulk density of tungsten was used for thermal conductivity calculation.

The hardness was evaluated on a universal hardness tester Nexus 4504 (Innovatest, NL) using Vickers indenter and load equivalent to $1\,\mathrm{kg}$.

3 Results and discussion

Fig. 1 shows the microstructure of the SPS tungsten consisting of fine tungsten grains. The different gray level areas in the micrograph can be attributed to the different grain orientation; however, this must be confirmed by EBSD in further experiments. The structure is very dense. Minor residual porosity and no evidence of original powder particle boundaries prove the suitability of the sintering conditions. For W2 sample the porosity was determined to be 0.2 %, for W4 0.3 % (see Tab. 1). Nevertheless, based on the SEM examination of the porosity structure, it was concluded that most of the pores belong to closed porosity and the true porosity number might be slightly higher. Thus, Archimedean method is not the most suitable for porosity determination in the case of SPS samples.

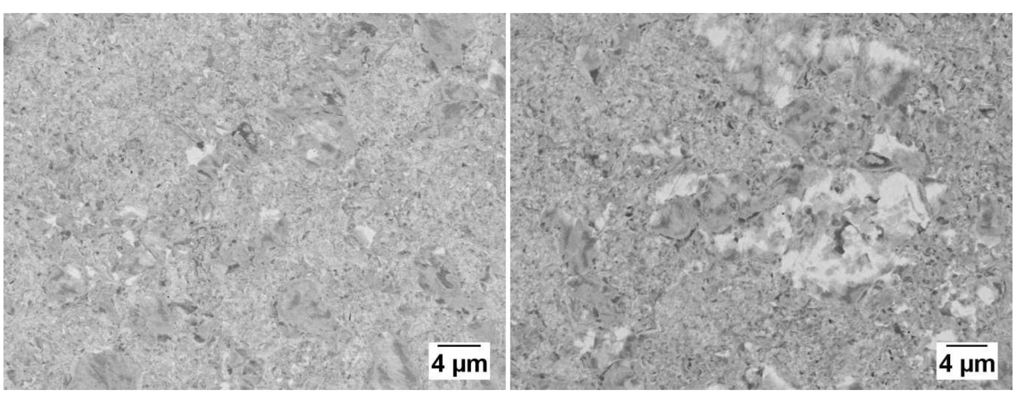

Figure 1: Microstructure of the SPS prepared W2 sample (left) and W4 sample (right).

The results of hardness measurements are listed in Table 1. Also hardness is higher for W2 sample; the reason might be again in different porosity; however, complementary information might be received from EBSD (grain orientation, grain size).

Table 1:

	W2	W4
Powder size/μm	2	4
Hardness/HV	373 ± 2	336 ± 5
Porosity/ %	0.2	0.3

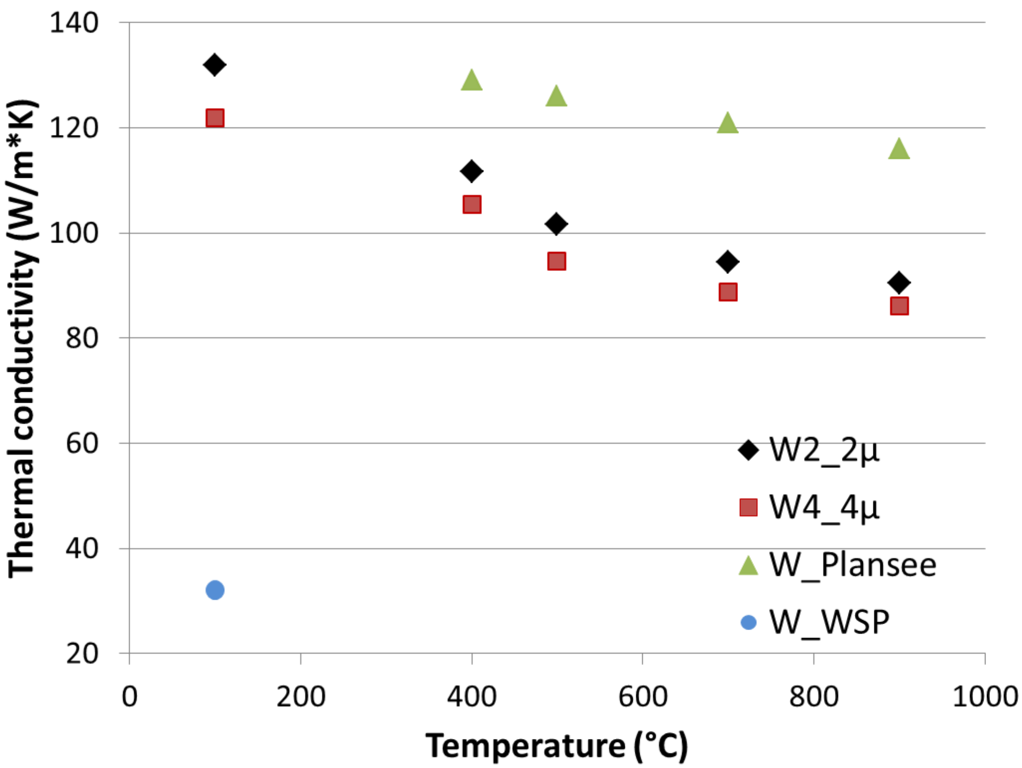

Figure 2: Thermal conductivity of W2 and W4

4 Conclusion

In this work, properties of spark plasma sintered tungsten produced from two powders of different sizes were studied. The feasibility of this technique for fast production of tungsten compacts was proved. The resulting compacts had very low porosity and high thermal conductivity. The difference in thermal conductivity was a result of different porosity amount and was apparent only at low temperatures. Improvement in the thermal properties can be achieved by further optimization of the sintering conditions.

5 Acknowledgment

This research was supported by Czech Science Foundation through grant no. P108/12/1872.

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