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Materials Science of PFM-W -- Current Status, Issues and Prospect --
「PFM-Wの材料科学　-現状、課題、そして展望-」

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Tungsten (W) is not a common structural material. The application of W as an armor material of fusion divertor is a big challenge. Many efforts of W-R&D have been made to overcome a number of requirements, among which fracture toughness is a critical issue. Materials science often played an important role in technology innovation as well as in understanding fundamental aspects. W-materials science certainly provides most suitable pass way to fabricate a reasonable divertor component with an enough ductility and resistance to irradiation and corrosion. Joining and irradiation performance will be the other issues for practical application.

1. Introduction

Materials are essential for any objects, and Tungsten (W) is not common as structural material mostly because of its brittleness, while W has high resistance against sputtering and low tritium retention [1].

Fusion plasma imposes so serious requirements to armor materials of divertor that there is no material to meet full requirements. W is one of the candidates, and W R&D for PFM has been performed with a lot of efforts to overcome critical issue to improve fracture toughness of W.

W has a body centered cubic (BCC) lattice similar to Fe, V, Nb, Ta and Mo, which have a characteristic feature of ductile-brittle transition (DBT) behavior in a temperature region. W is ductile at above DBT temperature (DBTT) that is as high as 400 °C [2], above which W is ductile. If the temperature of not only service but processing were always above the DBTT of the W, the critical issue of brittleness is solved irrespective of irradiation.

Generally, irradiation embrittlement is crucial for fusion structural materials. However, it may not be true for PFM-W because irradiation embrittlement usually appears at relatively lower irradiation temperature region and the temperature of the PFM can be kept above the DBTT by engineering design. Since irradiation embrittlement as well as transmutation helium embrittlement of W has not been fully understood, there are still uncertainties about the mechanism of irradiation and helium embrittlement [3,4].

In this presentation, current status, issues and future prospect are discussed to show a pass way to the fabrication of W-armored fusion divertor based on both materials science and engineering design technology.

2. Ductility improvement

Ultra-fine grained (UFG) W-(0.25-1.5)%TiC alloys with recrystallized, equiaxed grain sizes of 50-200nm and fine TiC dispersoids at grain boundaries were produced by powder metallurgy methods utilizing mechanical alloying processing. TiC was selected because of its high melting point (~3200°C) and a self-adjustment capability of the lattice constant by forming a solid solution with W and non-stoichiometric TiCx. UFG W-0.5TiC alloys exhibit negligibly small hardening by neutron irradiation, no blistering and flaking by 3MeV-He irradiation, and superplastic deformation by grain boundary sliding above 1400°C [5].

The new idea consists in synthesizing a W-laminate made of several layers of W-foils. During fabrication, the foil was exposed to a high degree of deformation and therefore, it is ductile. It can be bend plastically even at RT. The tensile properties at RT also show ductile behavior; however, they are anisotropic and strongly depend on the rolling direction [6].

A novel toughening concept based on W-wire reinforcement and the potential benefit of corresponding W-composites were demonstrated. This toughening method utilizes both, inherent toughness of W-wires and pseudo-toughness by energy absorption at the engineered wire/matrix interfaces [7].

3. Joining technology R&D

Oxide dispersion strengthened (ODS) steels and tungsten (W) are considered to be a desired couple of promising candidate as structural and plasma facing materials, respectively, of the first wall and divertor components in DEMO fusion reactor [8-10]. However, ODS steels and W show a significant difference in their physical properties, particularly the mismatch of coefficients of thermal expansion (CTE), W=4.3 × 10^{-6} K^{-1}, α-steel = 10.5 × 10^{-6} K^{-1}. Diffusion bonding is an attractive technique to obtain W-layered ODS steel component because of their availability of the sufficient thickness of the component and possible excellent interfacial strength. Two types of joints of ODS steel and W, liquid phase diffusion bonding (LPDB) and solid state diffusion bonding (SSDB), were produced and their joint microstructure and strength were investigated.

Nano-hardness distribution in the cross section of both joint regions, (a) LPDB and (b) SSDB (note the different hardness scale) are shown in Fig. 1. In order to evaluate the shear strength at joint region, the miniaturized torsion tests were performed at room temperature and the results are shown in Fig. 2. Both joint regions have little plastic strain.

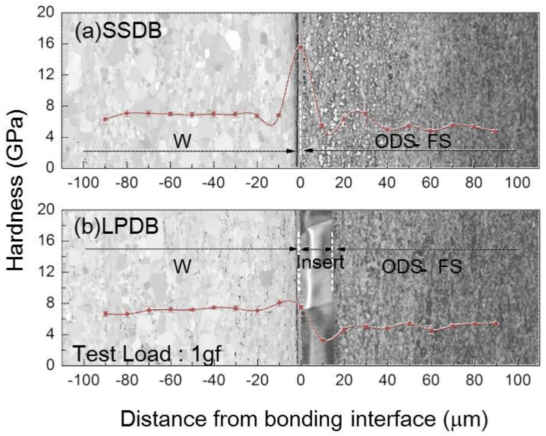

Fig. 1. Hardness distributions on the cross sectional area of W and ODS steel joint [11].

However, the shear strength of LPDB joint region is as high as 300 MPa and higher than that of SSDB joint region.

4. Materials science and engineering design technology

Material behavior of W is not very well understood based on currently available materials science and knowledge. It can be said, however, that there are several pass ways to reach the fusion divertor production. One is through the essence of materials science and the other is sophisticated engineering design technology. Both materials science and engineering design technology also include several methods which have been left for definite consideration. The best selection and combination of both the science and engineering certainly offer the most attractive divertor in near future.

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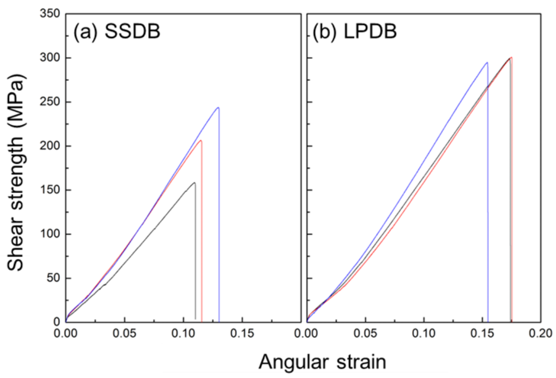

Fig. 2 The results of miniaturized torsion tests of W-ODS steel joints. Three tests were carried out for each joint [11].