Effect of fusion reactor relevant heat load on pure tungsten and its alloys for plasma facing components

1. Introduction

Tungsten (W) is the promising candidate of the plasma-facing material (PFM) for divertor in a fusion reactor because of its high melting point, high thermal conductivity, and high sputtering resistance. On the other hand, improvement of the material properties is desired to increase the reliability of W as PFM. In our previous works, we fabricated the W alloys (i.e. potassium (K)-doped W and K-doped W-3% rhenium (Re) alloy) to increase the mechanical properties, recrystallization temperature, and irradiation resistance of pure W [1-4]. The objective of this work is to investigate the applicability of K-doped W and K-doped W-3%Re under the fusion reactor relevant heat load condition.

2. Finite element analysis

This work calculates temperature and stress values and their distributions in the W monoblock for ITER divertor made of pure W, K-doped W, and K-doped W-3%Re during the heat load. A three-dimensional thermo-mechanical analysis was conducted for the W monoblock by the finite element analysis (FEA). The dimensions of the finite element model was based on W monoblock for ITER divertor, and its 1/4 model was used. The materials used in the analysis were W materials such as pure W, K-doped W, and K-doped W-3%Re, CuCrZr, and OFHC-Cu. CuCrZr and OFHC-Cu are the coolant channel material and the buffer materials between W and CuCrZr, respectively. The material properties of W materials were obtained from our previous experimental results and literatures. The anisotropy of the mechanical property of W materials was considered in this analysis. The material properties of CuCrZr and OFHC-Cu were based on the data obtained from JAEA and the literature. In this analysis, all materials were defined as perfect-elasto plastic solid. As a heat load condition, a heat flux of 10 - 20 MW/m² and a dwell time of 10 s were considered for the top surface of the W monoblock. The cooling water temperature was 25 °C, and its pressure was 2 MPa. The axial symmetry surface of the X and Y axes were fixed.

3. Results and discussions

Figure 1 shows the temperature at the top surface of W monoblock during the 20 MW/m² heat load. Maximum temperature in pure W and K-doped W was almost the same because of the thermal conductivity of K-doped W was almost the same with that of pure W. Although, the maximum
Temperature in K-doped W-3%Re was ~200 °C higher than other W materials because of its lower thermal conductivity.

Figure 2 shows the heat flux dependence of the depth of the area above recrystallization start temperature from the top surface of monoblock. In the case of pure W, the area above recrystallization start temperature was formed during 12 MW/m² heat load, and its depth was linearly increased with increasing heat load. In K-doped W and K-doped W-3%Re, depth of the area above recrystallization start temperature was smaller than that in pure W because of higher recrystallization start temperature. The K-doped W-3%Re showed highest resistance to the recrystallization due to its highest recrystallization start temperature (~1800 °C).

The difference of the stress distribution in each W materials during heat load was not significantly observed in this work. Large stress was observed at near the interface between W and OFHC-Cu, and plastic deformation was occurred. In W alloys, the degree of the plastic deformation near the OFHC-layer was smaller than pure W because of its better mechanical property of K-doped W and K-doped W-3%Re than pure W. These results suggested that the W alloys especially K-doped W-3%Re will show better resistance to the recrystallization and structural reliability than pure W under the heat load condition in fusion reactor.

4. Summary
The thermo-mechanical analysis of pure W, K-doped W, and K-doped W-3%Re monoblocks under fusion relevant heat load conditions were carried out. K-doped W-3%Re showed highest surface temperature than pure W and K-doped W, however, it shows highest resistance to the formation of the recrystallized area because of its highest recrystallization start temperature. K-doped W and K-doped W-3%Re shows lower degree of the plastic deformation during heat load than pure W.

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References