§18. Optimum Material Design of Tungsten for Plasma Facing Component Using Numerical Simulation

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1. Introduction

The solution hardening strengthening and dispersion strengthening are effective to improve the mechanical properties of tungsten for plasma facing material. However, degradation of the thermal properties occurs due to these strengthening treatments. Therefore, the balancing between the improvement and degradation of these properties is essential for the optimum material design as the plasma facing material.

The numerical simulation of the plasma facing component considering the actual structure and loadings is considered to be one of the solutions for this issue. The objective of this study is the optimum material design of the tungsten and its alloys by those strengthening methods based on the numerical structural simulation of the plasma facing component by using the material database developed by Tohoku University.

2. Numerical simulation procedures

The finite element analysis of the ITER divertor was carried out using the mechanical and thermal properties experimental database of the pure tungsten (PW), potassium-doped tungsten (KW) and potassium -doped tungsten containing 3% rhenium (KW3R).

The solver for the finite element analysis was the ANSYS v.15.0. The bullet perfectly plastic behavior after the yield point was assumed for the tungsten body and the piping component fabricated by the CuCrZr and OFHC-Cu. The heat load up to 10~20 MW/m^2 for 10 s was inputted to the divertor top surface. The heat loading and cooling times were 10 s and 20 s, respectively. The temperature and pressure of the cooling water were 25^{o}C and 2 MPa, respectively[1)].

3. Results and discussion

Fig. 1 shows the temperature distributions during heat loading up to 10 MW/m^2. The maximum temperature was observed not at the center but at the edge of the top surface of the divertor regardless of the material. Because the temperature dependence of the thermal conductivity of the PW and KW was very similar, almost no difference of the temperature distribution was observed between the PW and KW. On the other hand, the higher temperature was observed in the KW3R divertor. The maximum temperature was 2400^{o}C for the KW3R divertor, which was approximately 200^{o}C higher than that of the PW and KW diverters. The rhenium addition induces the reduction of the thermal conductivity of the tungsten, especially at the lower temperature range. Therefore the higher temperature of the KW3R divertor might occur due to this lower thermal conductivity of this material.

Fig. 2 shows the recrystallized area distribution during heat loading up to 20 MW/m^2. The recrystallization temperature was 1100^{o}C, 1300^{o}C and 1800^{o}C for the PW, KW and KW3R, respectively, which were determined by the hardness and grain structure change due to the heat treatment. The maximum depth of the recrystallized area for the PW divertor was approximately 8 mm from the top surface. On the other hand, that for the KW divertor was smaller (~6 mm), which showed the similar temperature distribution as the PW one, because of the higher recrystallization temperature than the PW. In the case of the KW3R divertor, the maximum depth of the recrystallized area was much smaller (~3 mm) because of the much higher recrystallization temperature than the PW and KW though the maximum temperature was higher than them. Based on these analysis results, the effect of the improving the recrystallization temperature by the rhenium addition had much more impact than the effect of the degradation of the thermal conductivity by that in the tungsten divertor.

1) M. Fukuda, S. Nogami, A. Hasegawa, K. Yabuuchi, K. Ezato, S. Suzuki, H. Tamura, T. Muroga, “Thermo-mechanical analysis of tungsten and its alloys monoblock divertor under heat load conditions relevant to a fusion reactor”, PFR., accepted.

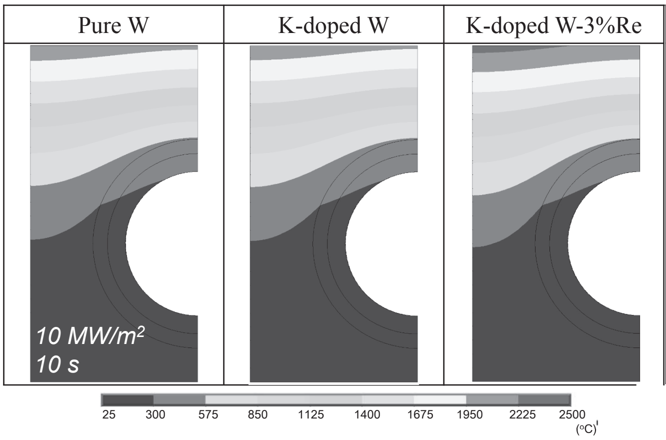

Fig. 1 Temperature distribution

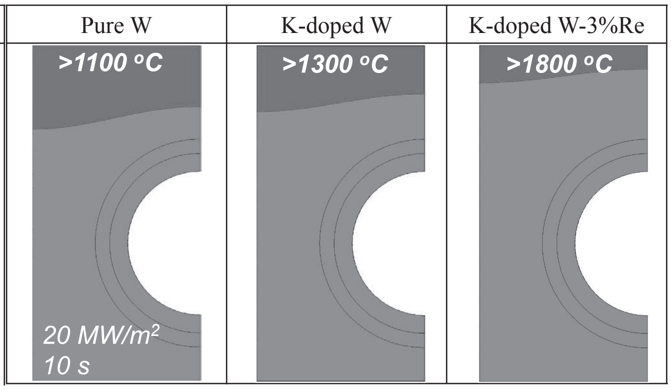

Fig. 2 Recrystallized area (red color) distribution