19PB-110

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

プラズマ対向機器用純W及びW合金に対する核融合炉実機相当の熱負荷の影響

Makoto Fukuda, Shuhei Nogami, Kiyohiro Yabuuchi, Akira Hasegawa, Koichiro Ezato, Satoshi Suzuki, Hitoshi Tamura, and Takeo Muroga

福田誠[1], 野上修平[1], 藪内聖皓[1], 長谷川晃[1], 江里幸一郎[2], 鈴木哲[2], 田村仁[3], 室賀健夫[3]

1) Department of Quantum Science and Energy Engineering, Tohoku University
6-6-01-2, Aramaki-Aza-Aoba, Sendai 980-8579, Japan
東北大学量子エネルギー工学専攻 〒980-8579 仙台市青葉区荒巻字青葉6-6-01-2
2) Japan Atomic Energy Agency
801-1 Mukoyama, Naka, Ibaraki 311-0193, Japan
日本原子力研究開発機構 〒311-0193 茨城県那珂市向山801-1
3) National Institute for Fusion Science
322-6, Oroshi, Toki, Gifu 509-5292, Japan
核融合科学研究所 〒509-5292 岐阜県土岐市下石町322-6

The applicability of tungsten (W) alloys as the plasma-facing materials in a fusion reactor was evaluated using thermo-mechanical analysis in this work. The evaluated W alloys were potassium (K)-doped W and K-doped W-3% rhenium (Re). The depth of the region above recrystallization start temperature in W monoblock during the 20 MW/m^2 heat load of for 10 s was decreased by the K and Re addition because of the increasing recrystallization start temperature by K and Re addition. Plastic deformation of W monoblock was suppressed by K and Re addition, and K-doped W and K-doped W-3%Re showed better ability as plasma-facing material in fusion reactor than pure W.

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-elastro plastic solid. As a heat load condition, a heat flux of 10 - 20 MW/m^2 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

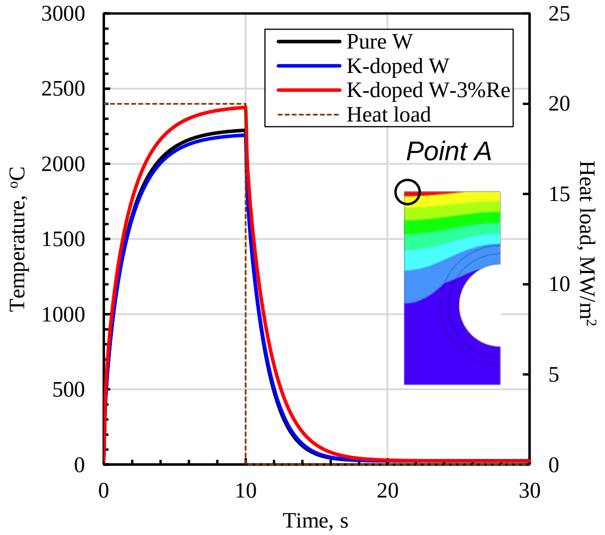

Fig. 1 Temperature change of W monoblock during 20 MW/m^2 heat load at selected point.

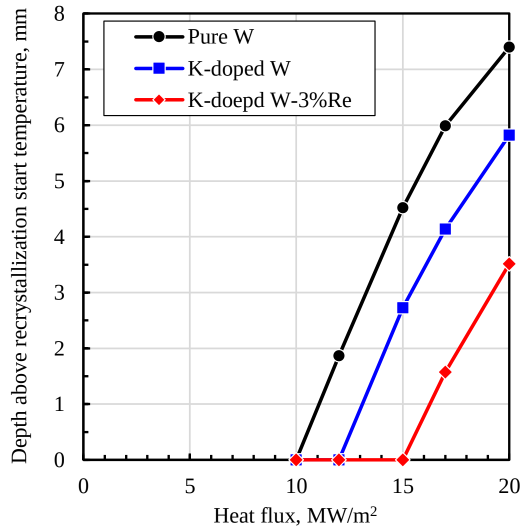

Fig. 2 Relationship between the depth of the area above recrystallization start temperature and the heat flux.

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/m^2 heat load, and its depth was lineally 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.

Acknowledgments

This work was supported by Grant-in-Aid for JSPS Fellows (26-3841) and NIFS LHD collaboration research program (NIFS14KERF024).

References

[1] M. Fukuda, T. Tanno, S. Nogami, and A. Hasegawa: Mater. Trans., **53**, 2145-2150 (2012).

[2] M. Fukuda, A. Hasegawa, T. Tanno, S. Nogami, and H. Kurishita: J. Nucl. Mater., **442**, S273-S276 (2013)

[3] M. Fukuda, S. Nogami, A. Hasegawa, H. Usami, K. Yabuuchi, and T. Muroga: Fusion Eng. and Des., **89**, 103-1036 (2014).

[4] A. Hasegawa et al.: presented in 25th Fusion Energy Conference (FEC 2014), Russia and to be published in Nucl. Fusion.