Enhancement of crack through the depth of grain growth on tungsten under transient high heat flux

Ki-Baek Roh [1], Nam-Kyun Kim [1], Jaemin Song [1], Kyungmin Kim [2], Myung-gun Lee [1], and Gon-Ho Kim [1]

[1]Seoul National University, Korea, Republic of

[2]National Fusion Research Institute, Korea, Republic of

High heat flux effect on the thermal damage of the tungsten is considered in this study for simulation of the divertor material in fusion reactor. According to the baseline operation, the stationary temperature of bulk divertor is under 1100^{o}C, that is lower than that of recrystallization for tungsten. However, Transient heat loading condition, ELM (Edge Localized Modes), can deliver high heat flux of 1 GWm^{-2} with transition time scaled of several tens of Hz on the strike point of the divertor. This transient heat load may cause the recrystallization of tungsten even though the steady state bulk temperature is lower than recrystallization temperature, resulting in the crack generation on tungsten surface. It may degrade and lose the armour property of divertor. In this study, we focused on the investigation of the mechanism of crack generation caused by surface material property changed due to the transient high heat flux loading while the bulk temperature is lower than the recrystallization temperature. For this experiment, ITER-grade double forged tungsten manufactured by Plansee was chosen as a target. Transient heat loading on target was carried out with a transferred arc plasma torch (SNU-THLT) having the rising and the fall time scaled of msec, respectively delivering the peak heat flux 0.2 GWm^{-2}, and repetition frequency is 30 Hz for each target exposure. Exposure time was 20 sec and 600 sec which correspond to 600 cycles and 18000 cycles of transient heat flux peak. Surface temperature of the target tungsten spiked as 2000^{o}C when arc plasma landed on the target. The temperature was measured by 2-color pyrometer during the transient heat loading. The width and depth measurement of the crack on tungsten surface was carried out by using FESEM (Field Emission Scanning Electron Microscope) and FIB (Focused Ion Beam). Arakcheev's model was adopted for qualitative analysis of the boundary condition of crack generation that is a function of DBTT, yield strength, young's modulus and temperature. The depth 6.3 μm and 1.5 mm crack was generated under the condition of 600 cycles and 18000 cycles relatively for the bulk temperature 1100 ^{o}C tungsten. Grain boundary angle distribution measured by EBSD showed recrystallization at 18000 cycles but not for the 600 cycles. Stress induced by single heat flux was 0.3 GPa that couldn't exceed yield strength 0.4 GPa. So, at the condition of non-plastic deformation, the mechanism for crack generation was fatigue induced by transient heat flux. From the SN curve which shows life time to failure along the loaded strain, tungsten surface should get failure at the repeated heat flux of 300 cycles. Recrystallized tungsten however, has different life time of failure. Although the same heat flux was loaded, 0.1 GPa was formed on the recrystallized tungsten because of the stress-strain curve degradation. So, the life time of failure of recrystallized tungsten decreased to 100 cycles which was relatively big difference with 18000 cycles of heat flux. From our recrystallization depth simulation, 1 GWm^{-2} and 10 Hz of ELM can cause the same recrystallization depth with our case in 1 min. So, the crack generation can be enhanced by recrystallization in the early phase of fusion operation.

This research is supported by the Brain Korea 21 Plus Program (No.21A20130012821). This research was supported by National R&D Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT & Future Planning(No. 2014M1A7A1A03045186). This work was supported by the Ministry of Science, ICT and Future Planning of the Republic of Korea under the Korean ITER project contract.