S1-3

Wプラズマ対向材料－He冷却ダイバータ機器の開発
Development of He-Cooled Divertor System and W Plasma Facing Material

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Our task, Task 1 of the PHENIX project focuses on characterizing the heat transfer in He-cooled W armor divertor concepts. The research objectives of this task are to (1) determine how changes in material properties due to neutron irradiation and T retention will affect the performance and safety margins for PFCs and armor materials such as W; and (2) establish the thermal-hydraulic performance of such divertor concepts. The major experimental facilities involved in this study are the High Heat Flux test station at the Plasma Arc Lamp facility at ORNL for measuring the thermal properties of armor materials, including irradiated specimens, and the He loop at the Georgia Institute of Technology for heat transfer test for the HEMJ test section shown in Fig. 1. The first 3 years of this task have focused on understanding heat transfer, due mainly to impinging-jet cooling using high-temperature and high-pressure He gas and high heat fluxes up to 6.6 MW/m^2. The latter half of this project will use this understanding, and the numerical models and analyses developed during the first half, to evaluate heat transfer through structural materials. The results from Tasks 2 and 3 regarding how the thermal properties of structural materials are affected by neutron irradiation, and possibly T retention, will be used to evaluate how such changes affect heat transfer and affect the cooling performance of He-cooled divertor concepts.

For heat transfer test, the correlation of Nusselt number *Nu* (heat transfer coefficient) with the non-dimensional gap width *H*/*D* was established for the design under the condition that *H*/*D* was 0.4-0.9 and the temperature of He was up to 300 °C. According to the correlation, removable heat flux for divertor prototypical conditions was optimized as 9.4 MW/m^2 at He temperature of 700 °C. To improve the cooling performance, heat transfer tests were performed at *H*/*D* less than that of HEMJ reference design. In the case of *H*/*D* = 0.25, the cooling performance increased by ~20% from the value for *H*/*D* = 0.5 when the jet temperature was less than 100 °C. By contraries, the cooling performance was degraded by max. 15% with increase in jet temperature higher than 200 °C in the *H*/*D* = 0.25 case as shown in Fig. 1 (b). The degraded cooling performance with increasing jet temperature is attributed to the laminarization due to highly accelerated flow near cooling surface. The cooling performance degradation is possible for

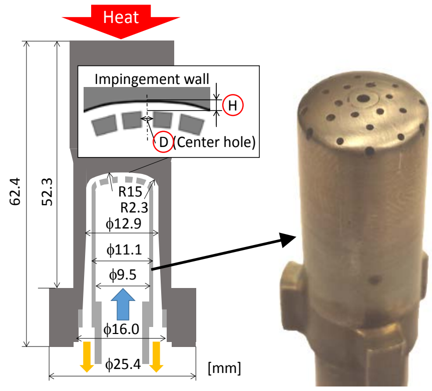


Fig 1. Cross-sectional view and inner cartridge of HEMJ test section

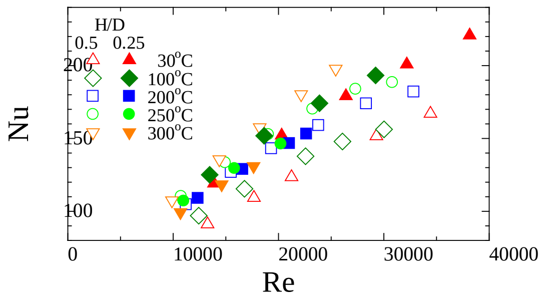


Fig 2. Effect of non-dimensional gap width on heat transfer performance of HEMJ

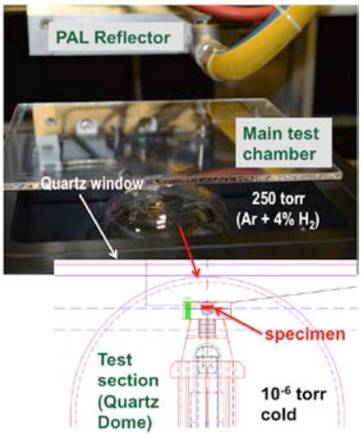
H/*D* = 0.5 and more wider spacing cases, because the temperature levels of both cooling surface and coolant become much higher in an actual divertor. By changing the jet configuration, the mitigation of highly accelerated flow region is required as well as development of turbulence model to predict the laminarization.

Assessing the effect of neutron irradiation of plasma-facing materials has been challenging due both to technical and radiological challenges. In an effort to address the radiological challenges, a new high-heat flux facility based on water-wall Plasma Arc Lamps (PAL) was developed at ORNL. In the first three years of the PHENIX program, the incident heat flux levels from PAL were limited to 3.3 MW/m^2. Following a reflector upgrade, the heat flux levels will be increased to 16 MW/m^2. As shown in Figure 1a, the use of PAL allowed the heat source to be separated from the test chamber, simplifying the safe testing of low activity level irradiated articles and materials under high-heat flux. The enhancement in the radiation safety during testing of irradiated specimens was accomplished by employing an additional, smaller hemispherical cap chamber, rated for high-vacuum systems, enclosing the cooling rod, specimen holder, and irradiated specimen as shown in Fig. 3. However, the high radioactivity of W and high cost of irradiation experiments limit the size of capsules used in fission test reactors and hence the geometry and size of neutron-irradiated specimens to several mm in thickness and less than 1cm in diameter. We called these specimens, small-and-thin material specimens (STMS). STMS specimens of vacuum plasma-sprayed (VPS) tungsten on F82H low activation steel were tested under high-heat flux using a PAL facility. Specifically, specimens were bolted onto a refractory metal holder that is attached to a water-cooled copper alloy rod. The effect of specimen bolting on the state of stress and deformation is not trivial for STMS, as the bolted area is not directly exposed to high-heat fluxes, resulting in possible non-uniform temperature distribution within the specimen. A thermo-mechanical model for the simulation of the energy transport and stress evolution for all the cycles during a HHFT was developed. The calculated temperatures for the top surface of the specimens and the back surface of the F82H are shown in Figure 1c for the first 24 HHF cycles of 10 s duration and absorbed heat fluxes of 1 to 1.41 MW/m^2.

Future studies include the evaluation of the thermo-mechanical effects during HHF testing for STMS. It is very important to quantify the stress distribution within the specimen during HHF testing in order to understand the materials science phenomena leading to changes in material properties due to HHF exposure. The state of stress-strain during HHF is also important for accurate material characterization of exposed surfaces, such as cracking and/or blistering.

In the remainder of the PHENIX program, neutron-irradiated W/SiC, W, W-K doped, and W-K doped +3 Re specimens will be tested at HHF of 10-16 MW/m^2. The W specimens will have a grain orientation perpendicular or parallel to the top surface. The properties of specimens will be fully characterized before and after HHFT in order to understand the materials science of the damage induced by the combined effects of neutron irradiation and HHF exposure.

(a)



(b)

Fig. 3. Main components of the PAL HHFT: (a) PAL reflector focusing the energy onto the test chamber, (b) setup of main test chamber and specimen

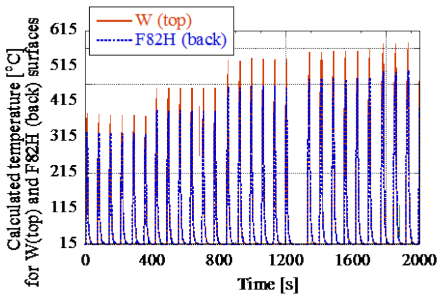


Fig. 4. Calculated temperatures for a thermal contact conduction per unit area between the F82H and Cu washer of 4,000 W/m^{2}K