4.4 HIGH-HEAT FLUX TESTING OF LOW-LEVEL IRRADIATED MATERIALS USING PLASMA ARC LAMPS —

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OBJECTIVE

The objective of this work is to test irradiated materials that are candidate divertor component materials and mock-up divertor components under high-heat flux conditions using Plasma Arc Lamps (PAL).

SUMMARY

The Research Safety Summary (RSS) was approved for high-heat flux testing of irradiated specimens. The radiation safety during high-heat flux testing was enhanced by the installation of a digital flow meter on the outlet part of the rod cooling circuit in order to monitor the flow rate during high-heat flux testing. One of the most difficult tasks is the measurement of sample temperature. The best data on sample temperature was obtained using a thermocouple welded to the sample during the high-heat flux testing. A pyrometer was used to measure the surface temperatures on either the specimen holder or the specimen. It was found that at high IR energies the pyrometer data is affected by the infrared energy from the PAL. Thus calibration runs are needed in order to enhance the accuracy of the pyrometer data.

PROGRESS AND STATUS

Effort was conducted on two main areas: (a) enhancing the radiation safety during testing of irradiated specimens and (b) enhancing the measurement accuracy of the sample temperature.

Results for enhancing the radiation safety during high-heat flux testing of irradiated specimens

The current efforts for enhancing the radiation safety during testing of irradiated specimens included:

- Installation of a water flow meter (0.2-2 gpm) to monitor the variation of coolant flow rate into the cooling rod.
- Installation of an automatic pressure controller – for Ar inlet and outflow - to regulate the vacuum pressure to approximately 4 psi in the test section during HHF testing to prevent the liftoff of main quartz window and escape of radioactive gases.
- Installation of a vacuum pressure transducer to monitor the vacuum pressure in the test section during testing and identify accidental vacuum leaks during HHF testing.
- A vacuum leak was repaired.
- In-situ data will be acquired for all experiments on coolant flow rate and vacuum pressure in the test section.

The coolant flow rate can now be measured in-situ for all experiments. As an example, the coolant flow rate was measured during high-heat flux testing consistent of five pulses. The flow rate monitoring will be used to assess the possibility identifying incipient boiling of the water that would lead to an overheating of the hottest section in the cooling rod. The PAL current for the 5 consecutive pulses was 700, 650, 625, 600, 600 A for 15 s, with a dwell time of 2 min between

pulses. The results show that the coolant flow rate drops by less than 2% during high heat flux testing (Figure 1), ensuring that the coolant does not exceed the critical heat flux.

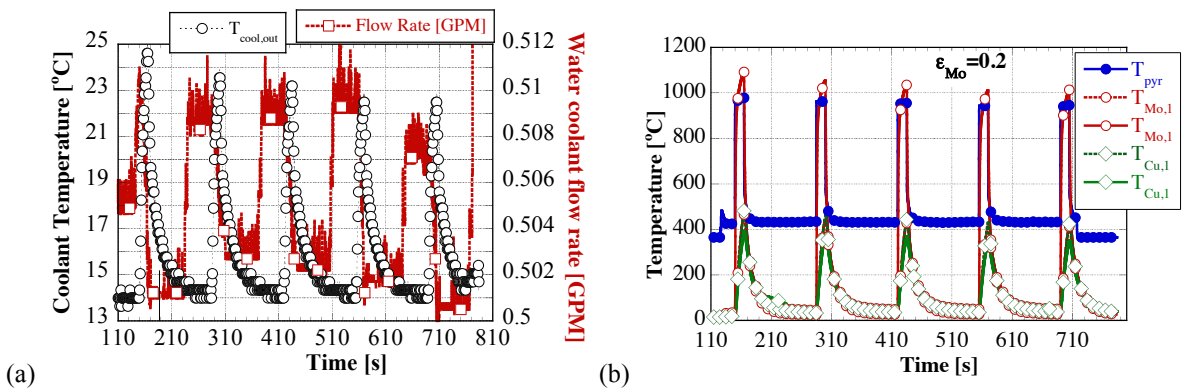

Figure 1. The variation of coolant temperature and coolant flow rate into the cooling rod was measured. (b) The variation of temperatures in the Mo holder during the five pulses.

Vacuum pressure was measured during HHF testing to insure that appropriate vacuum conditions are maintained. The results shown in Figure 2 show that appropriate vacuum pressure is maintained during typical HHF testing. The standard deviation of the pressure variation was found to be 0.09 psi during several pulses (while the mean vacuum pressure was 3.9818 psi).

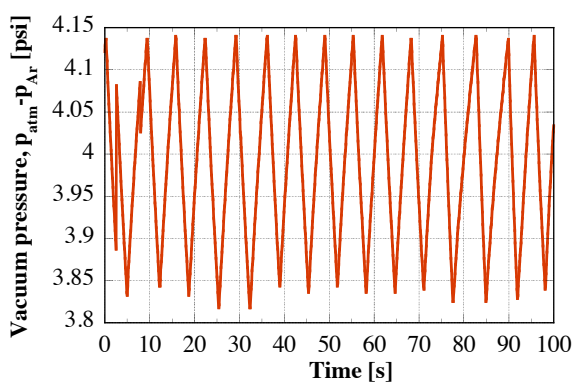

Figure 2. Vacuum pressure during 100 s of a typical test run.

Results for enhancing the temperature measurement

The current efforts for enhancing the temperature measurement during testing of irradiated specimens included:

- Assessment of pyrometer applicability in the actual PAL conditions.

- Use of a second generation of molybdenum specimen holder, for which the thermocouples could be installed closer to the backside surface of the specimen.
- Machining of 2G v2 Mo specimen holders with four thermocouples.
- Conduct calibration experiments in which the pyrometer was used to measure directly the temperature the W specimen surface while a thermocouple was welded on the backside of the W specimen.

The temperature variation during one pulse at 700A (roughly 70% power), for the thermocouples and pyrometer, are shown in Figure 3. The placement of thermocouple tips within the first generation of molybdenum specimen holder, 1G Mo, is shown for the sake of completion to aid in data interpretation (Figure 4a). The pyrometer aims at the sample holder side (Figure 4b) at an angle of 34° with the respect to the normal direction to the sample holder surface. The data shown in Figure 3 indicate the following:

1) The pyrometer data is affected by the infrared energy from the PAL during high-energy pulses. The proof of artifact is the sharp raise and drop in pyrometer temperatures right at the onset and end of pulses. The fact that the temperature varies during the high energy indicates that the reflections from the PAL into the pyrometer, which creates the artifact at high-energies, is not dominant and thus it can be corrected.
2) The pyrometer data is not affected by the infrared energy during the idle period, after the end of high-energy pulses. The pyrometer temperature at idle has the similar temperature ranges as those measured by thermocouples inserted in the 1G Mo holder.

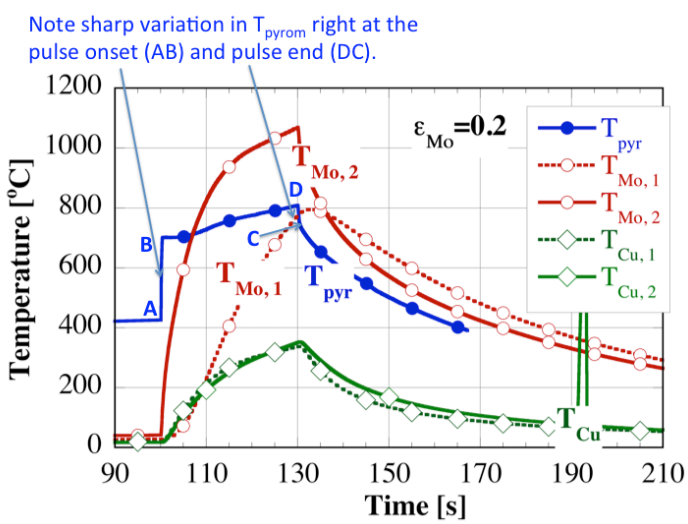

Figure 3. The temperature measured by the pyrometer on the side of Mo holder exhibits sharp variations right the onset and end of the energy pulse of PAL (one pulse of 30 s at 700 A).

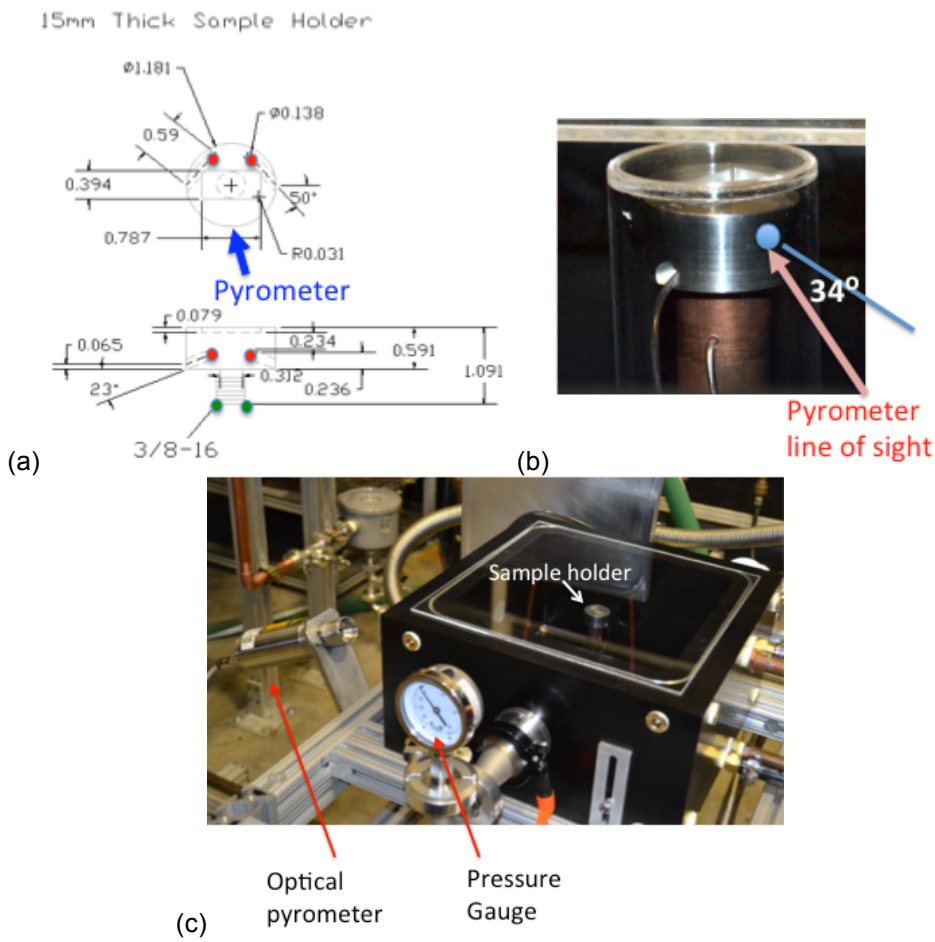

Figure 4. (a) The placement of the thermocouple tips, (b) pyrometer spot on the 1G Mo holder showing pyrometer spot size and direction with respect to the normal to the surface, and (c) pyrometer placement for the measurement of the Mo holder surface temperature.

Temperature data was obtained when the W specimen was placed in the second prototype of molybdenum specimen holder, or 2G Mo (Figure 5). Two holes were drilled in the 2G Mo holder contains for inserting thermocouples close to the back surface of the specimen. The 2G Mo holders have a conical surface and a cutout in order to reduce the heat flux absorbed in the testing fixture (Figure 6). During the HHFT, one thermocouple that was in contact with the W on its back side was bonded to the W specimen, providing one the best set of data for specimen temperature (showed in Figure 5 with open circle symbols). This data shows an actual increase from room temperature to 1,000s in the first 2 s. The sample-reflector distance was 2 cm, the incident heat flux was about 3.2 MW/m^2, while the absorbed heat flux was into the specimen was approximately 1.6 W/m^2 (50% of the incident heat flux).

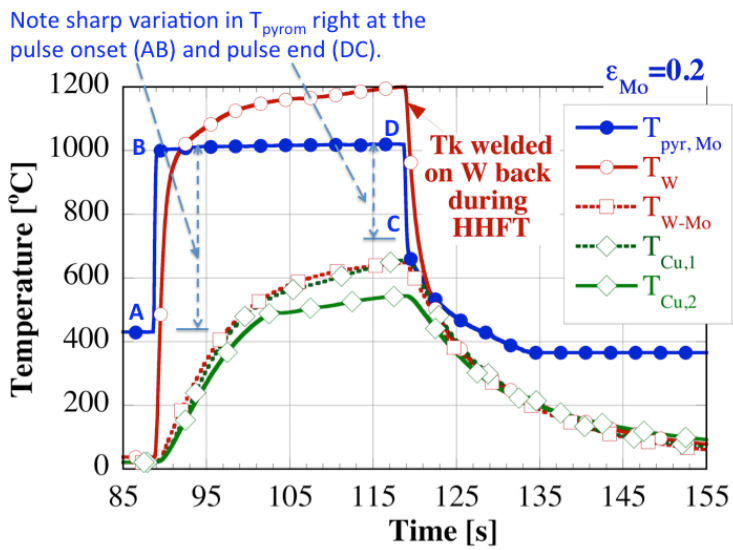

Figure 5. Temperature measured by the pyrometer on the side surface of 2G Mo holder ($T_{pyr,Mo}$) thermocouple welded on W specimen back surface during HHFT (T_W), thermocouple between W specimen and Mo holder (T_{W-Mo}), and thermocouples in the cooling rod at the ends of Mo holder thread (Figure 6). The sample was exposed to one pulse of 30 s at 800 A and the sample-reflector distance was 2 cm.

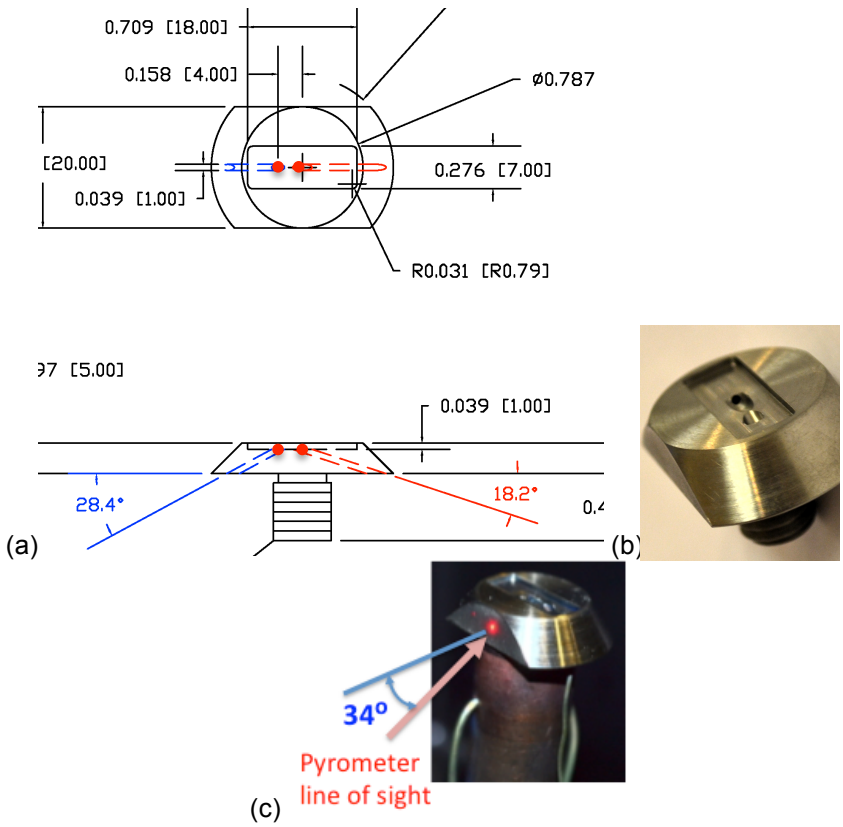

Figure 6. 2-nd generation of Mo specimen holder (a) dimensions; thermocouple tips are shown with red dots, (b) picture, and (c) pyrometer spot size and direction with respect to the normal to the surface.

Calibration experiments for the pyrometer temperature

Calibration experiments, in which the pyrometer was used to measure directly the temperature the W specimen surface, while a thermocouple was welded on the backside of the W specimen, were conducted. The pyrometer was mounted on a tripod and raised above the top level of the test section in order to allow direct line of sight to the sample. The pyrometer was inclined at 58° with respect to the vertical direction (Figure 7a). There were significant difficulties associated with welding the thermocouple tip to the W specimen, which is 0.5 mm thick. Other difficulties were due to the sample support, as it could not be laid down in the Mo sample holder. The sample was placed on a quartz plate, above a steel block, such that the distance between the reflector and sample surface was approximately 9 cm. The sample was not actively cooled as it laid on a quartz plate at an angle of 30° with respect to the quartz plate, making contact with the quartz plate on one edge (Figure 7b and 7c). In this arrangement the specimen was cooled mainly by thermal radiation to the ambient and by thermal conductance through the edge contact with the quartz plate. One minor disadvantage of this placement was the variation of the heat flux on the specimen surface due to its inclination from the horizontal. The laser spot that indicates the pyrometer measurement spot is also shown in Figures 7b and 7c with a red dot. In Figure 7, the temperature results from an experiment are shown. The incident heat flux

was about 0.46 MW/m^2 while the absorbed heat flux was into the specimen was approximately 0.23 W/m^2. After the experiments were conducted, it was observed that the specimen oxidized, a likely cause being the placement of the woven ceramic inside the test section to shield thermocouples from direct IR heating.

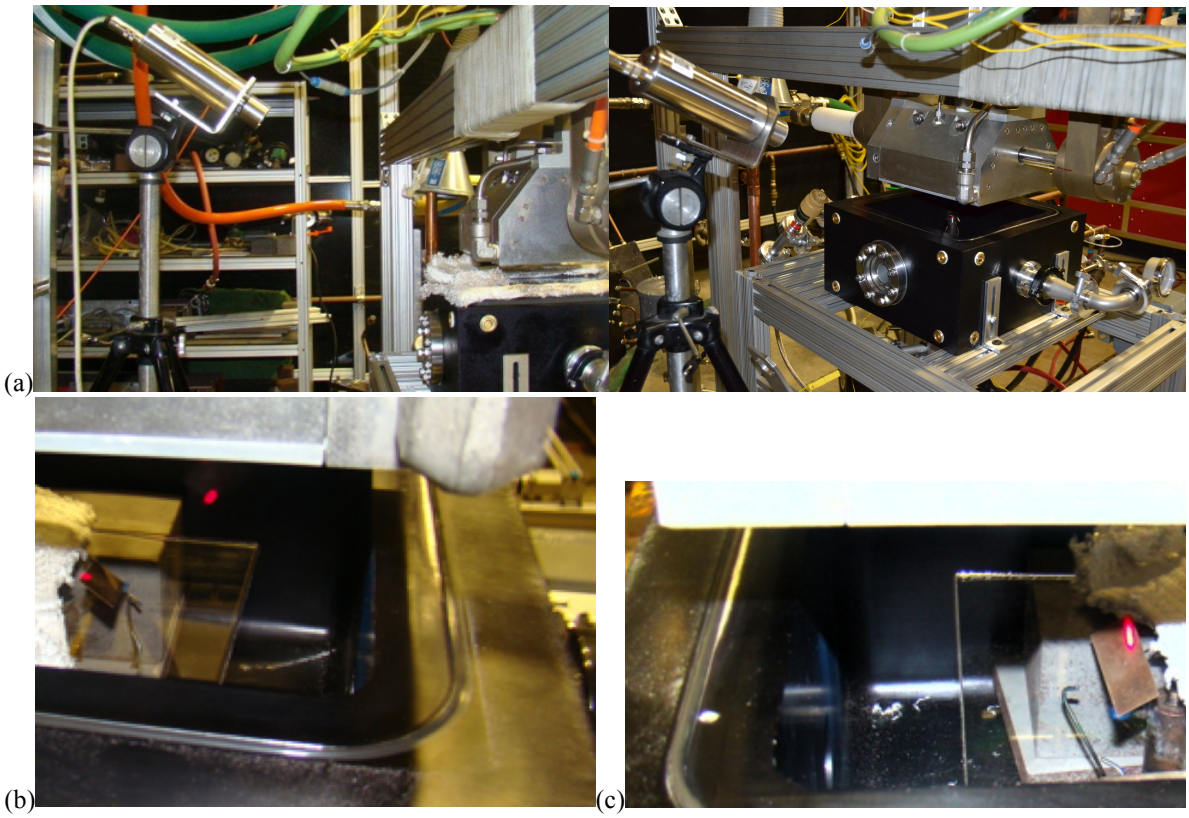

Figure 7. (a) Side view of the pyrometer mount in a raised position to enable direct line of sight to the specimen top surface. Laser spot marked with red color points to the pyrometer measurement spot: (b) side view and (c) front view – opposite side from pyrometer.

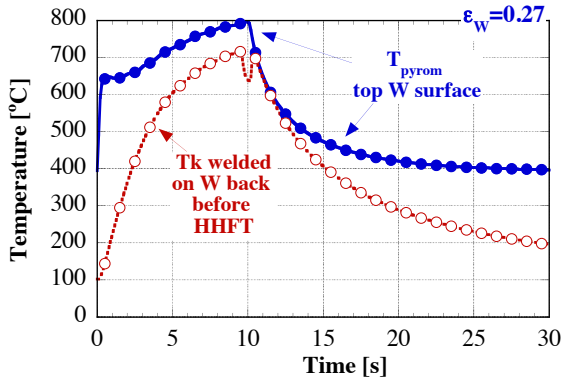

Figure 8. Temperature measured by the pyrometer on the top surface of an uncooled W specimen (solid circle symbols) and thermocouple welded on W specimen back surface before HHFT (empty circle symbols). The sample was exposed to one pulse of 30 s at 200 A.

ACKNOWLEDGMENTS

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