Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

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To cite this article: M Teshigawara *et al* 2018 *J. Phys.: Conf. Ser.* **1021** 012061

IOP Conf. Series: Journal of Physics: Conf. Series **1021** (2018) 012061 doi:10.1088/1742-6596/1021/1/012061

Present fabrication status of spare moderators and reflector in J-PARC spallation neutron source

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Abstract. Invar joint and Au-In-Cd decoupler were implemented to prepare spare moderators and reflector. Invar joint was developed to improve manufacturing procedure of the hydrogen transfer line. A low activation Au-In-Cd alloy also could be implemented in the neutron extraction beam hole of reflector as a substitute of Ag-In-Cd decoupler by taking into account of enlarged heat capacity according to actual size in the HIPing process.

1. Introduction

The structural material of moderators and reflector, such as an aluminum alloy, is going to reach to the design value (20 DPA) around 2020 by an accumulation of irradiation-damage at the spallation neutron source of J-PARC. Fabrication of the spare moderators and reflector was started in 2013 for the replacement. The fabrication of coupled moderator, reflector and reflector plug were almost completed.

In the original moderator design, a material combination of aluminum alloy (A6061-T6) and stainless steel (SS316L) were adopted[1, 2] to make the moderator vessel and the hydrogen transfer line with the cryogenic multi-layered pipe of 5th annular geometry. However, some troubles such as welding leak, deformation and contact with other pipes, etc, were occurred in the actual fabrication process[3] due to the thermal shrinkage measure in the hydrogen transfer line.

An idea was proposed to use an invar alloy into the hydrogen transfer line, because of very low thermal expansion, which is one order of magnitude lower than that of aluminum alloy or stainless steel. This would improve the fabrication procedure much simple to eliminate complicated asymmetrical preset considering a certain amount of dimensional change at a cryogenic temperature at an elbow-shaped bend. It was also utilized to make the H_2 transfer line in SNS ORNL[4].

Another new idea is that Gold(Au) was replaced to Silver of the Silver – Indium - Cadmium (Ag-In-Cd) composition as the decoupler material to reduce the residual radioactivity of the used components significantly without sacrificing neutronic performance[5]. The bonding between Au-In-Cd[6] and aluminum alloy (A5083), which is a part of structural material of reflector, was developed by adopting a Hot Isostatic Pressing (HIP) for small-sized-test-pieces (c.a. 25mm in diam.)[7]. However, there were critical engineering issues to make large sized bonding between Au-In-Cd (AuIC) and A5083 alloys required for the actual reflector. We have investigated the HIPing process in terms of the surface condition, size and heat capacity of large-sized AuIC. Finally, we

successfully implemented AuIC decoupler to the actual reflector assembly.
In this report, we report these results.

2. Spare coupled moderator fabrication

2.1 Coupled moderator fabrication

In order to utilize the invar alloy in the hydrogen transfer line, we developed the invar-joints for the conversion of invar alloy to aluminum alloy and stainless steel and evaluated the mechanical strength of invar-joints[5], which was also requirement for the Japanese High Pressure Gas Safety Law. These results were reflected the design of the hydrogen transfer line[8]. The invar joints are installed at parallel lines after converted from multiple pipes of hydrogen transfer line. The external shape is as same as original design except for including invar material.

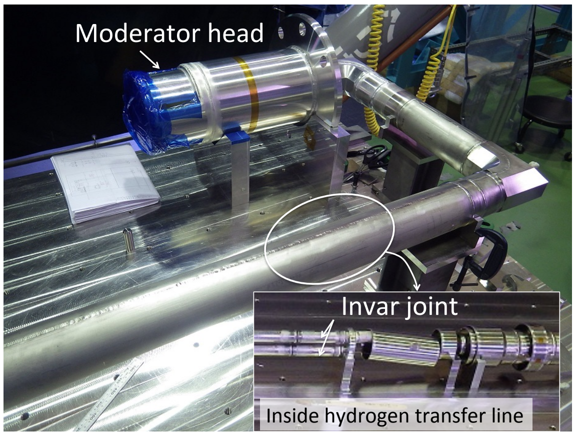

Fig. 1 Picture of coupled moderator manufacturing process

The length of multiple pipes from moderator head to the conversion position is c.a. three meters shorter as compared with original design. The thermal shrinkage could be also reduced from 20 mm to 2 mm. These might provide the benefit of eliminating the difficulty in the multiple pipe fabrication with asymmetrical setting.

The coupled moderator was fabricated based on the idea. The invar-SS316L joint was installed at parallel lines after converted from multiple pipes as shown in Fig. 1. The results of R&D[5] was also reflected the fabrication process of invar joint.

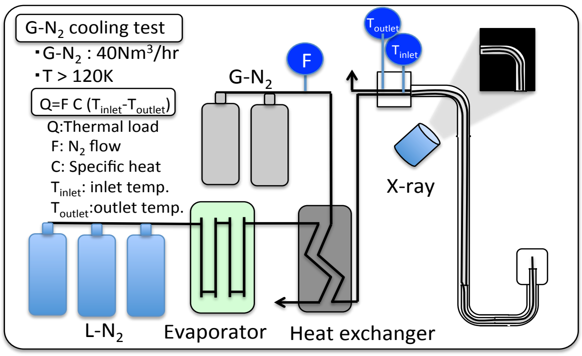

Fig. 2 Layout of cooling test of moderator

2.2 Cooling test of coupled moderator

After finished coupled moderator fabrication, the cooling test was conducted to confirm the design.

We measured the thermal load into the hydrogen transfer line and X ray transmission image to confirm inside hydrogen transfer line, such as the thermal shrinkage and welding defect. The layout of the cooling test is shown in Fig. 2. The gas-nitrogen (G-N_2) was applied to cool down hydrogen transfer line. Figure 3 shows the trends of the temperature and G-N_2 flow rate for case of 150K of inlet temperature. The inlet and outlet temperature was saturated c.a. 150 and 157K, respectively, with G-N_2 flow rate of 36Nm^3/hr in c.a.

Inlet temp. (K)	Thermal load (W)
150	71.7±12.8
140	77.8±15.2
130	79.7±15.1

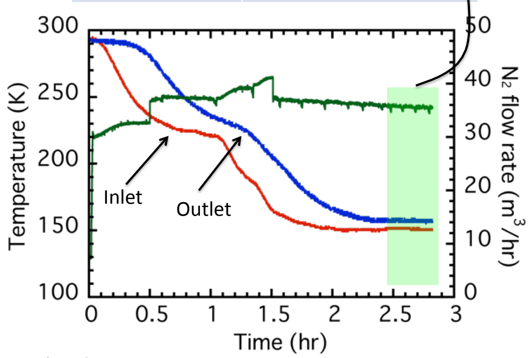

Fig. 3 Temperature and N_2 flow rate trends for measurement of thermal load

two hours from beginning of G-N_2 flow, giving c.a. 71.7 W of thermal load. The measured thermal load for other temperature cases are also shown in Fig. 3. These measure thermal load met with the design value [8].

Thermal shrinkage was measured at the elbow pipe mostly away (c.a. 4 m distance) from the fixed position of room and cold temperature, which is installed at inside coupled moderator head as shown in Fig. 1. Figure 4 shows X ray transmission image of hydrogen pipes for case of 140K as compared with room temperature case.

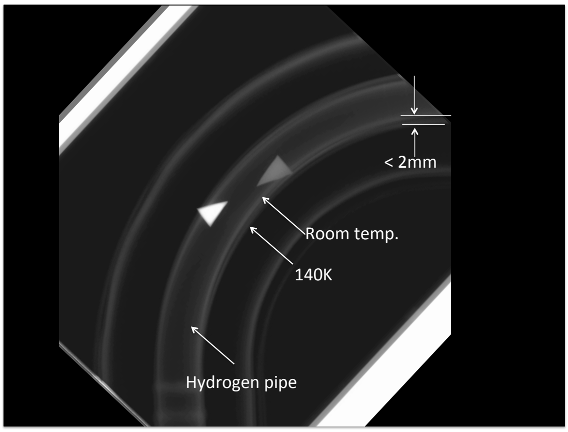

Fig. 4 X ray transmission image of hydrogen pipes for case of 140K as compared with room. temperature case

The measured thermal shrinkage was c.a. 2 mm, which was approximately as same as estimated one in the design calculation. It was also fond that the no welding defect was detected in X ray transmission, which was taken along the hydrogen transfer line.

3. Spare reflector fabrication

As described in Sec. 1, previous study[7] gave an optimal HIPing condition for small sample (c.a 100g in total). The decoupler is installed along the inner surface of beam extraction holes in a reflector assembly as shown in Fig. 5. HIPing method was applied to make the neutron extraction beam holes with decoupler. Before HIPing, the AuIC decoupler material is contained in canning container together with A5083 and SS304 blocks, resulting in 224 + 307 kg in total. This enlarged heat capacity due to actual size might affect on inside temperature profile during HIPing process, especially for bonding strength between AuIC and A5083 alloys. We considered that it takes longer time to reach the required HIPing temperature due to the enlarged heat capacity of the actual HIPing volume. We found the suitable HIPing condition (Pressure: 100MPa, Temperature: 535℃ and Holding time: 2 hours) for actual sized HIPing by numerical simulation and experiment. This detailed result will be discussed somewhere.

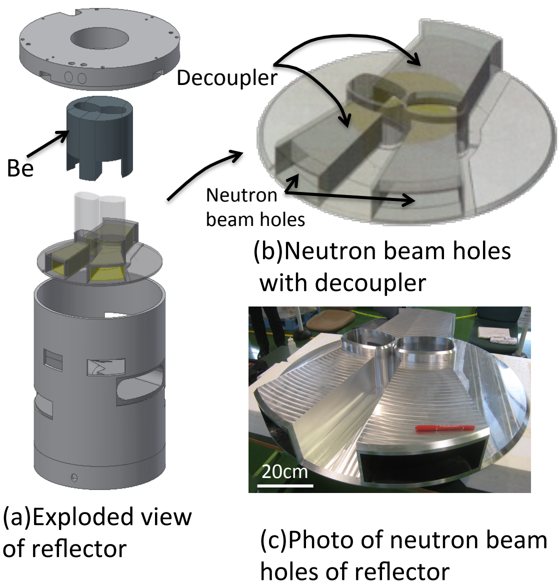

Fig. 5 Exploded view of reflector(a), Neutron beam holeswith decoupler(b) and photo of neutron beam holes of reflector(c).

HIPing was conducted under this condition. HIPed one was machined to parts of reflector with beam holes as shown in Fig. 5 (c). Ultrasonic inspection was conducted to detect the separation of bonding area between AuIC and A5083. No separation was detected at whole area including AuIC. Typical ultrasonic inspection data is shown in Fig. 6. The reflections were detected for each boundary, such as A5083, AuIC and A5083. The thickness for each boundary was 15.5, 2.7 and 1.3 mm, respectively, which was satisfied the design condition. The thickness (2.7mm) of AuIC was converted using sound velocity of AuIC. Finally, the machined parts were integrated into a middle part of the reflector by the welding.

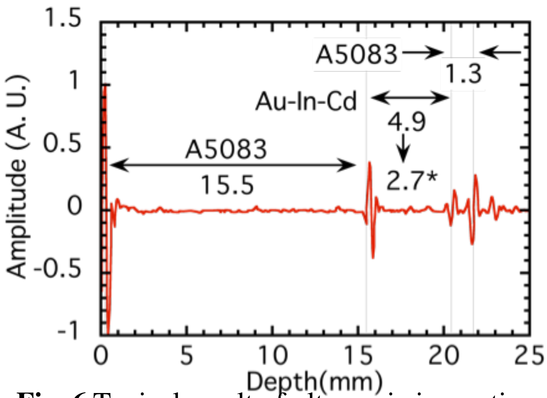

Fig. 6 Typical result of ultrasonic inspection between AuIC and A5083.

4. Assembling test

All moderators, reflector and reflector plugs are connecting at locating pins using remote bolts by remote control machine in hot cell for the installation in target station[9]. The installation error is less than 1.5 mm for each component in our design to satisfy the required performance. We performed the assembling test of coupled moderator and reflector by using the crane and hands on as shown in Fig. 7. We confirmed that each component could combine at locating pins without any rattling and stress and we also confirmed the installation error satisfied with required design.

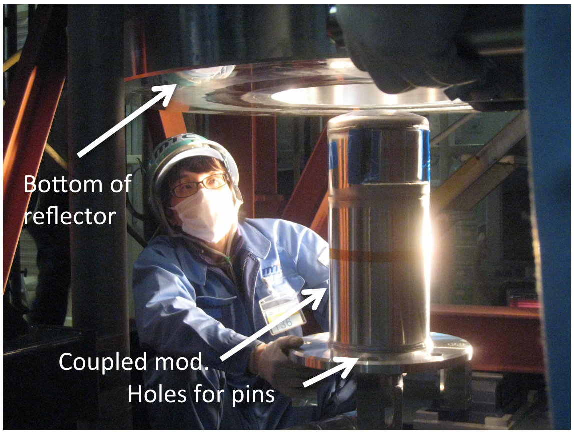

Fig. 7 Insertion of coupled moderator into reflector in assembling test

5. Summary

Invar joint and Au-In-Cd decoupler were implemented to prepare spare moderators and reflector for the replacement around 2020. Invar joint was developed to improve manufacturing procedure of the hydrogen transfer line. A low activation Au-In-Cd alloy also could be implemented in the neutron extraction beam hole of reflector as a substitute of Ag-In-Cd decoupler by taking into account of enlarged heat capacity according to actual size in the HIPing process.

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