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Development of Mechanical Sealing and Laser Welding Technology to Instrument Thermocouple for Nuclear Fuel Test Rod

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1. Introduction

To measure the centerline temperature of a nuclear fuel in pile, a C-type thermocouple that can be used at a high temperature of above 1500˚C must be mounted using instrumentation methods at the top or bottom of a nuclear fuel test rod [1]. Zircaloy-4 of the nuclear fuel test rod, AISI 316L of the mechanical sealing parts, and the MI (mineral insulated) cable at a thermocouple instrumentation are hetero-metals, and are difficult to weld to dissimilar materials. Therefore, a mechanical sealing method to instrument the thermocouple should be conducted using two kinds of sealing process as follows: One is a mechanical sealing process using Swagelok, which is composed of sealing components that consists of an end-cap, a seal tube, a compression ring and a Swagelok nut [2]. The other is a laser welding process used to join a seal tube, and an MI cable, which are made of the same material. The mechanical sealing process should be sealed up with the mechanical contact compressed by the strength forced between a seal tube and an end-cap, and the laser welding process should be conducted to have no defects on the sealing area between a seal tube and an MI cable. Therefore, the mechanical sealing and laser welding techniques need to be developed to accurately measure the centerline temperature of the nuclear fuel test rod in an experimental reactor.

This paper describes not only the results on the mechanical sealing and laser seal tube welding tests to instrument the C-type thermocouple, but also the results on the insulation and circuit resistance measurement, the helium leak test, and the metallography analysis to confirm the soundness of the test specimens.

2. Experimental

The materials of the specimens used for the performance tests are the Zircalloy-4 for the cladding tube and end-cap and the AISI 316L for the mechanical seal parts and MI cable. The Zircalloy-4 is zirconium alloy containing minor additions of Sn in a solid-solution in a hexagonal close-packed phase (HCP) with minor additions of Fe, Cr, and/or Ni present in fine second phases [3]. The size of the cladding tube is 9.5mm in outer-diameter and 8.36mm in inner-diameter, and that of the end-cap is 9.5mm in outer-diameter, 5.5mm in inner-diameter, and 25mm in length. The AISI 316L is chromium-nickel stainless steel added with molybdenum to increase the corrosion resistance and mechanical properties, and has high tensile strengths and outstanding weld-ability. In addition, it is the lower carbon material of AISI 316. The size of seal tube of a welding part is ø2.0mm in outer diameter and ø1.0mm in inner-diameter, and 26.5mm in length. The outer-diameter of MI cable connected with a thermocouple is ø1.0mm. The views of Swagelok sealing components and the microstructure of the mechanical sealing area for a nuclear fuel test rod instrumented with a thermocouple are given in Fig. 1.

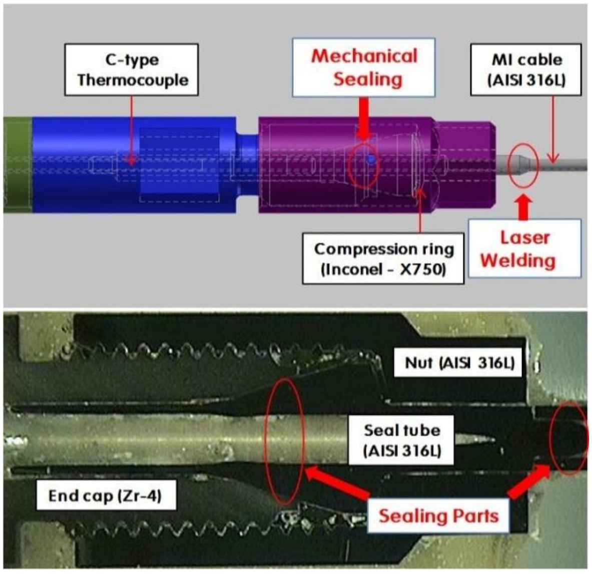

Fig. 1 Swagelok sealing parts and microstructure of mechanical sealing area for a nuclear fuel test rod instrumented with a thermocouple.

To establish the torque value for sealing the Swagelok, the mechanical sealing tests were performed according to the torque variables of a Swagelok nut fastened by a torque wrench (TOHNICHI Co. CL25N5x10D) that can set up the torque values. To obtain the laser welding conditions, the laser welding tests for welding a seal tube and a MI cable was carried out without the filler metal by a laser welding system and under the five process parameters, such as the laser power, laser pulse repetition, and the turn speed of the welding specimen. To analyze the specimens tested by the mechanical sealing and laser welding processes, circuit soundness tests for the MI cable, helium leak tests, and metallographic analyses were carried out for all test specimens.

3. Results and discussions

3.1 Mechanical sealing

The mechanical sealing test using the Swagelok to instrument a thermocouple in a nuclear fuel test rod was carried out with various torque parameters (10~25 N/m) by a torque wrench. The torque wrench is presented to the required torque value of the application, and it then signals the user when the torque is achieved. To seal the mechanical sealing part between an end-cap and a seal tube, the optimum torque value established of the Swagelok nut is 17.5 N/m.

3.2 Laser welding

The laser welding system consists of a laser source (YLR-150/1500-QCW-AC model made by IPG co.), a laser head, a 3-axis (X, Y, Z) servo stage, an index chuck (θ), and a control PC. Its welding process is conducted as follows: First, a specimen is fixed in an index chuck. Second, the laser welding conditions of the laser welding system are set up. Finally, the start button is turned on. Fig. 2 shows the specimen fixed in a rotary chuck, and the welding surface between a seal tube and MI cable sealed by the laser welding system to establish the laser welding conditions.

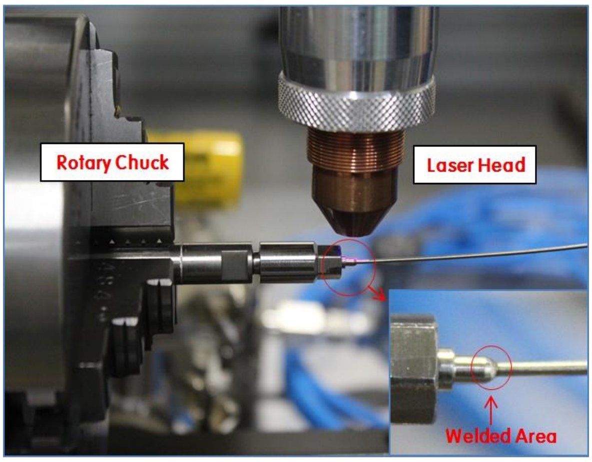

Fig. 2 Specimen fixed in a rotary chuck of the laser welding system and sealing surface sealed between a seal tube and an MI cable

The laser welding tests were conducted under various welding conditions, and the results have shown a good welding performance at a welding power of 750W (50%), a repetition of 6Hz, a rotate speed of 3.6rpm, a focus length of 171.5mm and a shield gas (helium) flow rate of 20L/min.

3.3 Soundness confirmation

To confirm the soundness of specimen surfaces welded by a laser welding system, a visual inspection was carried out by a microscope. The insulation resistance of the MI cable tested with the mechanical sealing methods to confirm electrical verification was measured using a Megger (SM-8220). The insulation resistance values of all samples fulfilled by the mechanical sealing and laser welding tests were more than 10GΩ. The soundness of these specimens tested using a torque wrench having a ranch and welding system was confirmed through helium detection tests and microstructural analyses for all sealing specimens.

4. Conclusions

The mechanical sealing and laser welding tests were conducted to develop the thermocouple instrumentation techniques for the nuclear fuel test rod. The optimum torque value of a Swagelok nut to seal the mechanical sealing part between the end-cap and seal tube was established through various torque tests using a torque wrench. The optimum laser welding conditions to seal the welding part between a seal tube and an MI cable were obtained through various welding tests using a laser welding system. The soundness of the fuel rod specimen sealed by the mechanical sealing and laser welding was confirmed through electrical verification, helium leak tests, and microstructural analyses.

Acknowledgement

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