End Plug Welding of New FM Cladding Tube for SFR Metallic Fuel Rod

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1. Introduction

A sodium-cooled fast reactor (SFR) system is among the six systems selected for Gen-IV promising systems and expected to be deployed in 2020 [1]. In Korea, the R&D on a SFR has been begun since 1997, as one of the national long-term nuclear R&D programs. As a fuel for SFR, metallic fuel, U-Zr alloy fuel, was selected and is being developed. The operating environment of a SFR core is severe. The peak cladding temperature is about 650℃ and the neutron flux can reach up to 200 dpa. Thus, ferritic/martensitic (FM) steel such as HT9 has been selected for a SFR fuel cladding tube material because of the excellent irradiation characteristics [2,3]. But the HT9 material is not enough to satisfy the discharge burnup goal due to the high coolant outlet temperature and the low creep resistance. Recently new FM steel is under development to improve HT9 material properties. At KAERI, development of new FM steels, named FC92B and FC92N, has been in progress to improve thermal creep resistance. In this study, the qualification test of the end plug welding of new FM steels, FC92B and FC92N, for SFR metallic fuel rods was carried out based on the developed HT9 welding technology [4]. Through the qualification test, the end plug welding of new FM steels was well verified.

2. Characteristics of SFR metallic fuel

Fig. 1 shows the specifications and dimensions of SFR metallic fuel assembly which is under development at KAERI. The composition of the fuel is U-20%TRU-10%Zr for the closed fuel cycle and U-10%Zr for a prototype reactor. As shown in this figure, a fuel assembly is composed of a nose piece and a handling socket at the both ends, and a hexagonal duct in the middle part which contains 217 fuel rods assembled inside it [5]. Each fuel rod has a lower end plug, a fuel slug, an upper gas plenum, and an upper end plug as shown in Fig. 1. The outside of fuel rod is wrapped with a wire. In inside of fuel rod, the gap between fuel slug and fuel cladding is filled with sodium (Na). In principle, a closed fuel cycle is based on recycling spent fuel discharged from pressurized water reactor, which means the handling of high radioactive materials. Since americium (Am) is a strong gamma emitter, and curium (Cm) a high neutron emitter, the fabrication of TRU bearing metallic fuel needs to be performed in a remote control fabrication facility in a shielded hot-cell with sufficient radiation protection. Moreover, all the fabrication works should be performed in an inert atmosphere, because of the high reactivity of the handling materials like Uranium (U), Plutonium (Pu), and Sodium (Na) metals.

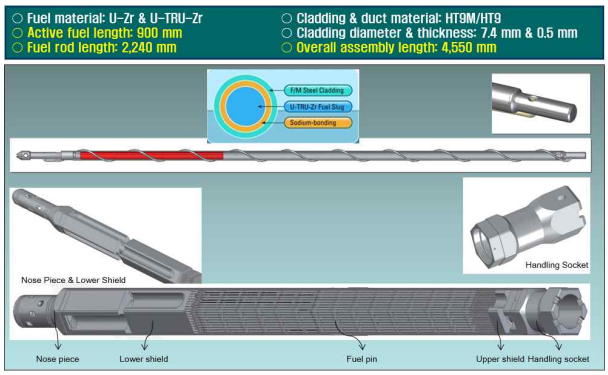

Fig. 1 SFR metallic fuel

3. End Plug Welding

There are many commercialized welding techniques such as GTAW, electron beam welding (EBW), and laser beam welding (LBW) as a sort of fusion welding and resistance upset butt welding, percussion welding, and flash welding as a sort of solid state welding. Among them, a resistance upset butt welding is now used for the end plug welding of PWR fuel elements and CANDU fuel rods in a commercial basis. The end plug welding method should be selected and developed in consideration of weldability, weld joint design, production efficiency, etc. For end plug welding of SFR metallic fuel rod, the welding technique, welding equipment, welding conditions and parameters were developed. The GTAW technique was adopted and the welding joint design was improved. And the optimal welding conditions and parameters were well established as reported before [4].

4. Qualification Test

4.1 Qualification test plan

The end plug welding of SFR metallic fuel rod is a special process according to the Quality Assurance Program and the regulation KEPIC (Korea Electric Power Industry Code). Thus, the qualification test has to

be done to prove the weld quality of end plug welding of SFR metallic fuel rod. The following qualification test plan and procedures were applied to the welding of new FM steels.

- Welding 15 weld specimens by GTAW
- Visual inspection
- X-ray radiography
- Selecting 10 weld specimens for quality evaluation
- Measuring dimensions for 5 weld specimens
- Metallographic examination for 4 weld specimens
- Burst test for 3 weld specimens
- Tensile test for 3 weld specimens

For the evaluation of the end plug weld quality, the following quality criteria were applied.

- The fabricated fuel elements shall meet all dimensions described in the drawing.
- The end plug to tube weld shall have tensile and burst strengths equal to or greater than those of the tube material.
- The weld joint between the end plug and tube shall consist of sound metal, the effective length of which, in the radial projection, shall be no less than 90% of the tube thickness.

4.2 Qualification test results

Based on the developed welding technology, welding equipment, welding conditions and parameters [4, 5], 15 weld specimens were prepared with the following welding parameters.

- Stick-out : 0.7 mm
- Weld current : 30A
- Rotation speed : 30 rpm

Fig. 2 weld specimens prepared by GTAW

According to the qualification test plan and procedures, the weld quality evaluation tests were conducted and the following test results were obtained.

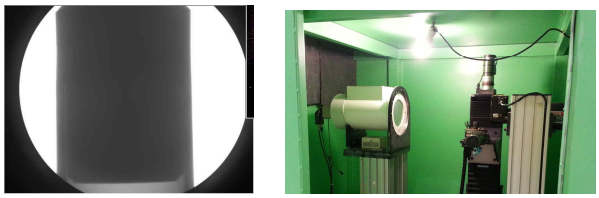

Fig. 3 X-ray radiography result on the weld part

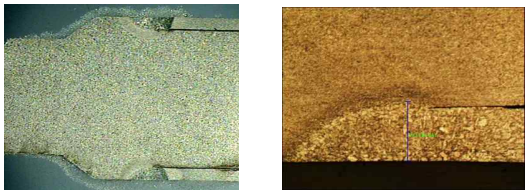

Fig. 4 Metallographic examination result on the weld part

Fig. 5 Burst test result

Fig. 6 Tensile test result

As shown in Fig. 2-6, the results of visual inspection, X-ray radiography, metallographic examination, burst test and tensile test satisfied the quality criteria by ruptured in the cladding tube part, not weld part. And also it was not found any defects in dimension measurements. As a result of the qualification test, the weld quality of end plug welding of new FM cladding tubes, FC92B and FC92N was qualified and the welding process is ready to produce SFR metallic fuel rods under the qualified conditions.

5. Conclusions

Through the qualification test, the weld quality of end plug welding of new FM cladding tubes, FC92B and FC92N, was evaluated according to the qualification test plan and satisfied the requirements on the weld. Consequently, the qualified welding process is ready to produce SFR metallic fuel rods.

ACKNOWLEDGEMENTS

This work has been carried out under the Nuclear Research and Development Program supported by the Ministry of Science, Ict and Future Planning in the Republic of Korea.

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