Preliminary Study on Laser Beam Welding for Fabrication of SFR Fuel Rod

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1. Introduction

The long-term R&D on a sodium-cooled fast reactor (SFR) was begun in 1997, and a Prototype Generation-IV Sodium-cooled Fast Reactor (PGSFR) is being developed under the Gen-IV collaboration program. As a fuel for PGSFR, metallic fuel, U-Zr alloy fuel, was selected and is being developed. And U-TRU-Zr fuel development is under way in combination with the pyro-electrochemical processing of spent PWR fuel [1]. For the fabrication of SFR metallic fuel rods, the end plug welding is a crucial process [2,3]. The sealing of end plug to cladding tube should be hermetically perfect to prevent a leakage of fission gases and to maintain a good reactor performance [4]. In this study, based on the GTAW technique, the laser beam welding was preliminary evaluated as an end plug welding method for the end closure of SFR metallic fuel rods.

2. Features 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.

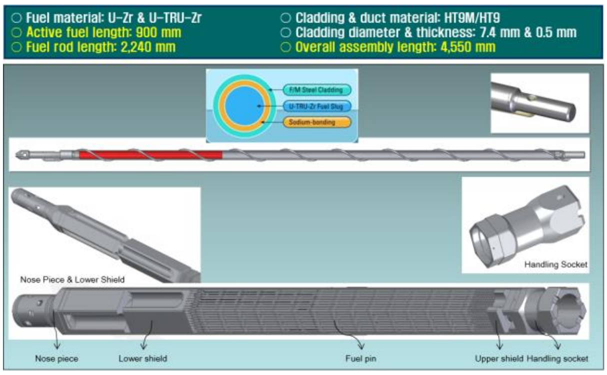

Fig. 1. SFR metallic fuel.

3. Laser Beam Welding

There are many commercialized welding techniques such as GTAW, electron beam welding (EBW), and laser beam welding (LBW) as fusion welding techniques and resistance upset butt welding, percussion welding, and flash welding as solid state welding techniques. 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 scale. For the fabrication of TRU-bearing SFR fuel rods, the end plug welding method should be selected and developed in a consideration of remote operability in a shielded hot-cell. In the case of laser beam welding, the equipment is simple and the welding procedures are not complicated because of using optical fiber for transmission of laser beam, but the weld defects like undercut or pin-hole occur occasionally due to the features of fusion welding.

3.1 Experimental methods

Fig. 2 shows the Nd:YAG LBW system (Model HBL PF-500N) used in this experiment. The peak power is 10 kW and the average power is 500 W. Table 1 shows the major chemical composition of the FM steel cladding tube material (HT9) used in this experiment. The weld specimens were prepared based on the SFR fuel rod dimensions.

Table 1. Major composition of HT9 steel. (wt%)

	C	Cr	Mo	W	Si	B
HT9	0.2	12	1.0	0.5	0.25	0.01

Fig. 2. LBW system used in this experiment.

End plug welding was conducted at the normal weld conditions; beam pulse frequency 15 Hz, laser power 500 W, welding speed 1.54 mm/sec. After welding, PWHT(Post Weld Heat Treatment) was conducted on the weld part at normal PWHT conditions. Fig. 3 shows the weld specimens welded by LBW.

Fig. 3. The weld specimen prepared by LBW.

3.2 Results and Discussions

For the evaluation of the weld quality, the following inspections were conducted.

- Visual inspection
- X-ray radiography
- He- leak testing
- Dimension measuring
- Metallographic examination
- Tensile test
- Burst test

The inspection results were obtained as shown in Fig. 4 to Fig. 8. The results showed the weld integrity meet the requirements of end plug weld part according to the quality control criteria.

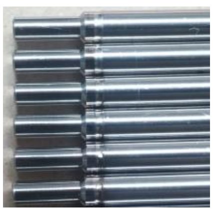

Fig. 4. Visual inspection results.

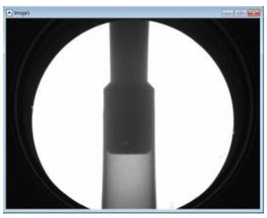

Fig. 5. X-ray radiography results.

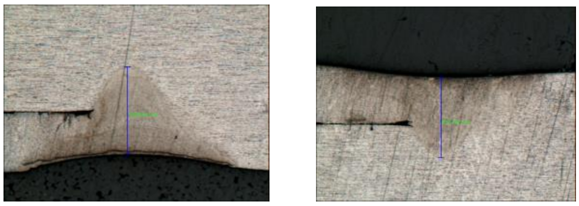

Fig. 6. Metallographic examination results.

Fig. 7. Tensile test results.

Fig. 8. Burst test results.

As shown in Fig. 4 to Fig. 8, the results of visual inspection, X-ray radiography, metallographic examination, tensile test and burst test satisfied the quality criteria on the weld. And also it was not found any leakage in a helium leak test. As a result of the weld inspections, the weld quality of end plug weld part welded by LBW was proved to be in good weld integrity.

5. Conclusions

The laser beam welding of SFR fuel rod was successfully carried out under the appropriate QA program. The results of the quality inspections on the end plug weld met the quality criteria on the weld. Consequently the laser beam welding is a good welding method as a one of the options for the end closure welding of SFR fuel rods.

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