Transactions of the Korean Nuclear Society Autumn Meeting
Jeju, Korea, October 21-22, 2010

Fundamental Study of Zircaloy-4 Tube Welding Using a Fiber Laser

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1. Introduction

The irradiation test of Zircaloy-4 tube specimens using a LVDT(Linear Variable Differential Transformer) for the pressure and elongation was planned for the evaluation of a nuclear fuels performance.[1,2] To establish the fabrication process, and for satisfying the requirements of the irradiation test, an LBW(Laser Beam welding) machine using a fiber laser source was developed, and the preliminary welding experiments for optimizing the process conditions of the specimens of Zircaloy-4 cladding tube to LVDT housing part were performed. Small tubes with a 12.12mm diameter and a 0.6mm wall thickness have been used and the optimum conditions of the circumferential welding have also been selected.

This paper describes the experimental results of the LB welds of the specimens of Zircaloy-4 small tube and the metallographic examinations of the LB welded specimens for various welding conditions for the fuel irradiation test. These investigations satisfied the requirements of the fuel irradiation test using a radiation-resistant LVDT for the pressure and elongation and the LB welds for the specimens of the small tube at the HANARO research reactor.

2. Materials and Results

2.1 Test Materials

For the instrumented capsule fabrication of the irradiation test, all the specimens were composed with Zircaloy-4 cladding tubes. For the housing parts using a radiation-resistant LVDT[3], the configuration of the specimens was also prepared as shown in Fig. 1.

2.2 Welding Machine

The welding machine was designed as shown in Fig. 2 by using a LBW process with the pulsed type in order to achieve a circumferential welding. A laser welding system is under development and consists of a welding head, monitoring vision system and rotary index. At this time, the laser source for tube welding was a FIBER LASER of 150 watt average power with an optical fiber transmission.

2.3 Examination Procedure

The macro-sections of Zircaloy-4 tube specimens were investigated by a metallographic examination to determine the penetration depth of the cladding tube. The welded specimens using the cladding tubes were polished and etched electrically with the following etchant : H_2O 90%, oxalic acid 10% (Vol.%).

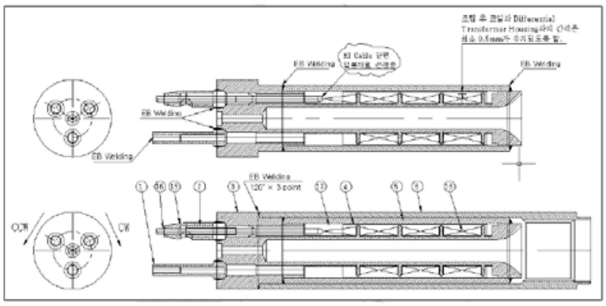

Fig. 1. Configuration of LVDT tube and housing specimen

Fig. 2. Photography of a laser welding machine

2.4 Investigation of the Zr-4 tube welding

The autogenesis melting method has a significant effect on the tube welding. If the solidification of the weld pool is brought about only in one direction while welding, it can be easily melted. Usually, an LB welding causes a molten pool in the material more easily than the other welding methods, and a deep penetration can be made by a fiber laser source. Fig. 3 shows the macro-sectional views of the upper and lower sides during the circumferential welding. As shown in Fig. 3, the lower side of the weld zone was found to have a much larger penetration, when compared with the upper side of the weld zone. Moreover, an LB welded zone usually had a smaller melting volume compared with the other welding methods, which melt by a high density energy. The small tubes sampled from the position of the inner tube were welded by the welding parameters and the configuration size as shown in Table 1. In this experimental result of the cladding tube specimens to LVDT housing part as shown in Fig. 4, the laser data for a Zircaloy-4 tube welding was proposed for the instrumented fuel irradiation test. As a result of examining the characteristics on penetration depth of the Zircaloy-4 welding by a fiber laser, it was found that the optimum parameters of the circumferential welding would be at least 50 watts of base average power and 10J of a pulse per energy to be welded.

Table 1. Welding parameters for a Zircaloy-4 tube specimen

	Pulse width	Pulse frequency	Ar gas (UPC grade)
Welding Conditions	5 (ms)	5 (Hz)	25 liter/min.

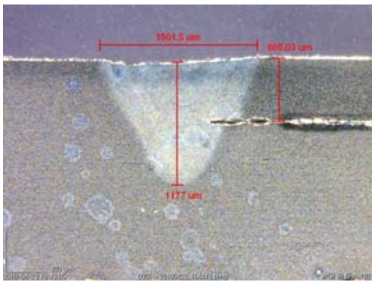

Fig. 3. Macro-section of a laser welded specimen

2.5 Observation of the microstructure using a Zircaloy-4 welded specimen

The variation of microstructure for typical Zircaloy-4 welds as seen in an optical microscope in comparison with its micrograph is represented in Fig. 4. The observation in which the weld metal solidifies is also considered. The fact that melting occurs implies that the base metal is locally welded to its melting point, and this has certain repercussions concerning the microstructure of the base metal. Since the weld zone was locally heated and cooled to the extent of its phase boundary areas depending upon the welding parameters, it had various microstructures with different phase transformations. It was observed that the α grains in the microstructure of the base metal of the Zircaloy-4 tube were longitudinally elongated, and the microstructure of the base metal of the Zircaloy-4 tube was an irregular structure with equiaxed, recrystallized α grains. The microstructures of the LB weld metals are shown in Fig. 4. The LB weld zone was also composed of a mixed structure of nonparallel Widmänstatten plates and martensite. The HAZ in the welds included a transformed structure with irregular grains near the weld metal.

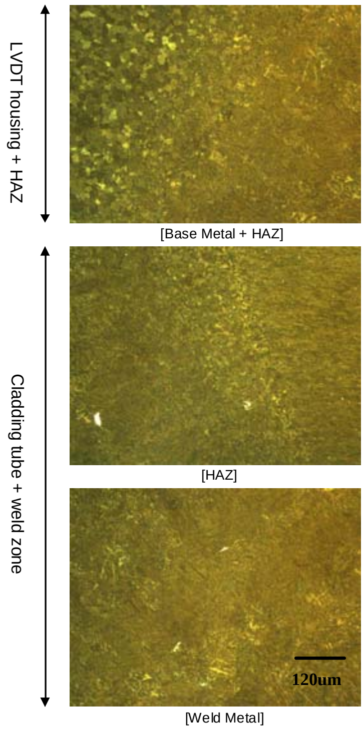

Fig. 4. Microstructure of a Zircaloy-4 welded specimen

3. Conclusions

Satisfactory LB welding technology of the cladding tubes to LVDT housing parts for the fuel irradiation test was developed. The Zircaloy-4 tubes of the LB welded specimens were free of defects and had good penetration depths of a cladding tube on the circumferential types respectively. Based on this fundamental welding experiment, instrumented capsule fabrications will be provided for the fuel irradiation test at the HANARO research reactor.

Acknowledgements

This work was supported by the Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST).

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