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Effects of laser welding conditions on microstructure of weld & HAZ in HT9 steel for fuel rod end-cap welding

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1. Introduction

A Sodium-cooled Fast Reactor (SFR) is a reactor operated by high-energy neutrons that enables it to recycle the spent fuel from a conventional light water reactor. The development of remote fuel fabrication technology for a SFR has been started that can be directly applied to a remote fabrication process of TRU fuel. The remote welding technology is one of remote fuel fabrication process that used to a fuel rod end-cap welding and fuel rods bundle assembly in a highly radioactive environment, so the direct human access is not possible. This technology can also be applied to practical use and commercialization of TRU nuclear metal fuel in near future. The purpose of this study is to find out the most suitable welding technology for the end-cap remote welding process and optimize its welding condition. In this study, candidate technologies for remote welding technology development were investigated and analyzed, and the advantages and disadvantages of each technology were analyzed. The purpose of this study is to find out the most suitable welding technology for the end-cap remote welding process and optimize its welding condition. In this study, candidate technologies for remote welding technology development were investigated and analyzed, and the advantages and disadvantages of each technology were analyzed. Finally, the final candidate technology was selected to investigate the welding conditions and welding results. As a candidate technology for remote welding, GTAW, friction welding, and disc/fiber laser welding technology were selected, and characteristics of each technology were analyzed and final candidate technology was selected. As a result of the technical review, it was evaluated that the laser welding technique is the most suitable for the remote welding technique. Among them, the fiber laser welding method was evaluated as the most suitable technique for the remote welding. Therefore, laser welding was performed by varying the welding output and the welding linear velocity in order to set the optimal conditions for the fiber laser welding technique. The microstructural (OM) and mechanical properties (hardness test, tensile test) were evaluated for each condition, respectively. In addition, the microstructure of HAZ were evaluated by Electron Back-Scatter Diffraction (EBSD).

2. Experimental Procedure

KAERI has manufactured a ferritic-martensitic cladding tube (HT9) in cooperation with a domestic steelmaking company. The end-cap has been also manufactured using the same materials.

End-cap welding process performed by selecting the conditions of the laser welding by changing laser output and welding speed as shown in Table 1. In addition, both CW (continuous wave) and pulse welding methods were used at 250 W, 39 and 53 rpm.

Table 1. Conditions for laser welding

Power(W)	150	200	250	300	350
39 rpm (0.9m/min)			o		
53 rpm (1.2m/min)	o	o	o	o	o
65 rpm (1.5m/min)			o		

Microstructure observations were conducted using optical microscopes and StreoScope. Specimens for these observation were prepared by a grinding and polishing up to 0.25 ㎛ power, followed by etching using an etchant of 95 ml water + 3 ml nitric acid + 2 ml fluoric acid. To investigate the overall distribution of the carbides and to analyze the individual carbide particles in detail, carbon extraction replicas technique was employed. The etched specimens were then carbon coated, and the replicas were released by an electrochemical method with 1.6V in a solution of 90 ml methanol + 10 ml Hydrochloric acid. Thin-foils and carbon replicas were examined using JEOL JEM-2100FX

Mechanical properties were evaluated using vickers microhardness test (HM-122) and tensil test (INSTRON-3367). Vickers Microhardness test was carried with load of 500g.

The grain size and misorientation distributions were observed by by Electron Back-Scattered Diffraction (EBSD) using a JSM-700F field-emission scanning electron microscope.

3. Results and Discussion

The microstructure evaluation of welded specimens was carried out to obtain the best process conditions for

LBW process. Figure 1 shows a photograph of the surface of a welded specimen analyzed by a Streoscope for each LBW output. As described above, when the welding process is carried out in an argon atmosphere, the welding width is increased when the welding power is increased by 250 W or more, and even if a small amount of oxygen is present. It was confirmed that oxidation occurred in the catalyst. When the surface texture was compared with the welding speed, it was confirmed that the oxidation occurred on the surface part as the welding speed decreased.

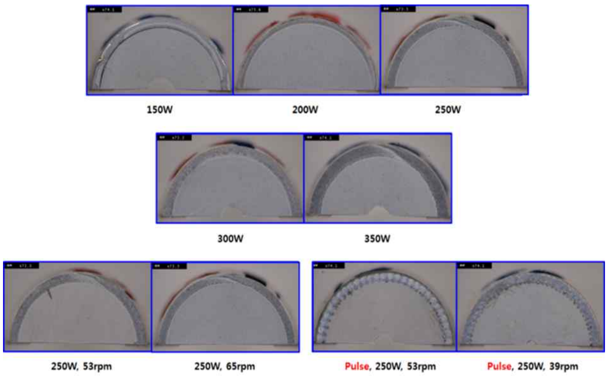

Fig. 1. Welding defect observations of weld specimens

Figure 2 shows the cross section of the welded part with respect to the welding speed and pulse welding conditions. In case of welding speed of 39, 53RPM, no weld defect was observed inside, but if welding speed increased to 65RPM, it was confirmed that weld defect occurred inside. In case of pulse welding method, it was confirmed that welding defect of several tens of μm was formed between the welded part and the welded part as observed with the stereoscope. Considering the welding defects as a whole, the welding power was maintained at 250W or less, the welding speed was kept at 53RPM or less, and the use of the CW welding method was judged as a process condition that did not cause weld defect.

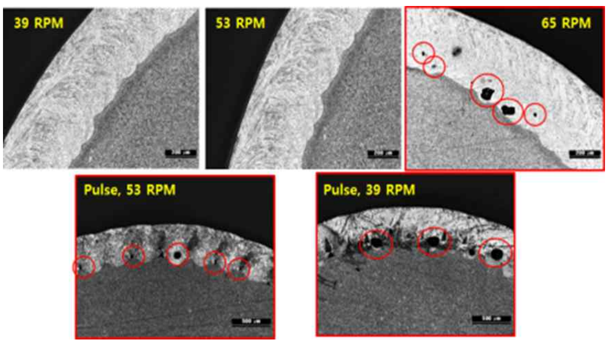

Fig. 2. Optical micrographs of the weld specimens

From the viewpoint of the weld depth, it was confirmed that the weld is formed at a depth of 0.5 mm or more, which is the thickness of the cladding tube, at a laser output of 250 W or more. The hardness characteristics of weld heat affected zone are as follows. First, the average hardness value of the base material part is about 250 Hv, and in the case of heat affected zone, the average hardness value reaches 500 Hv or more when reaching the weld part which gradually increases at 250 Hv and forms the martensite structure. Based on the results of hardness measurement, comparing the size of the weld heat affected zone (HAZ) according to the welding power, the HAZ of about 130μm area was formed at the welding power of 150W. It is confirmed that the HAZ is formed in a very wide region of about 300μm. In the case of such a HAZ, the hardness characteristics of the HAZ are lower than those of the base material. Therefore, the smaller the area of the HAZ, the better the welding characteristics. From this viewpoint, it is considered that the direction of reducing the welding power is advantageous for welding.

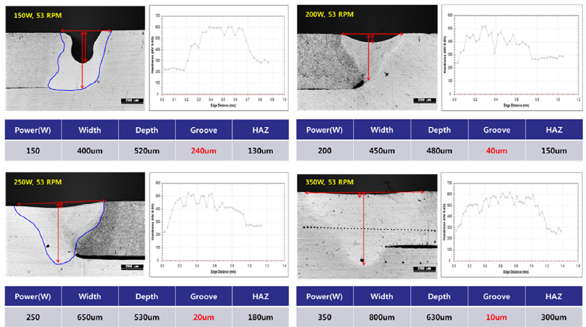

Fig.3. Effects of welding condition on Vickers hardness on HT9 end cap weld & HAZ.

4. Summary

In this study, comparison of the microstructure and mechanical properties on HT9 steel with various laser welding conditions were carried out. When considering the effects of weld structure and defects, weld depth, groove, and HAZ, the welding conditions of 250W and 53RPM were considered to be the most ideal conditions for the fuel rod LBW.

Acknowledgement

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