Analysis of a Remote Multi-pin Welding for a DUPIC Fuel Fabrication

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1. Introduction

An analysis of a multi-pin remote welding for a DUPIC fuel fabrication was made to establish the optimum welding processes in a hot cell environment. An initial investigation for hands-on fabrication outside the hot cell was performed, and the constraints of a hot cell welding were considered[1]. Generally a gas tungsten arc welding (GTAW), laser beam welding (LBW), friction welding (FW), and resistance welding (RW) process were assessed as candidates for this application. Preliminary welding performances to improve the RW process were also examined. The RW process was determined to be the best in a hot cell environment for joining the end plate to the end caps. The greatest advantage of RW would be a qualified process for spot weldments for which there is extensive production experience.

This paper presents an outline of the developed RW machine for a DUPIC fuel fabrication and compares the characteristics of a Zr-4 end plate welding by using electrical resistance and LB methods. The weld nuggets of RW specimens and torque strengths of resistant and LB welded zones were also investigated.

2. Welding Machine and Results

2.1 Test Materials

For the multi-pin specimens of a DUPIC fuel fabrication, all the specimens were prepared with Zr-4 end plates and end caps by using RW and LBW respectively as shown in Fig. 1.

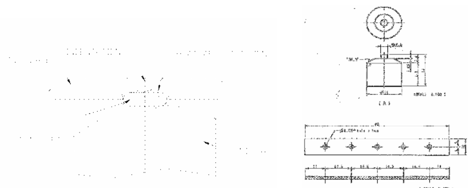

Fig 1. Configuration of the RW and LBW specimens.

2.2 Welding Machine

Remote welding machine was developed by adopting a head torch in order to achieve a spot weld metal between the end plate and the end cap, as shown in Fig. 2. The RW machine consists of a weld head torch, rotation indexer and specimen inserter. The torch head of the weld machine used the multi-pulse type method.

2.3 Examination Procedure

The macro-sections of the weld specimens were analyzed by a metallograph to determine the nugget size of the Zr-4 end plate to the end cap. All the welded specimens were polished and etched with the following etchant : H_2O 45%, HNO_3 45%, HF 10% (Vol.%).

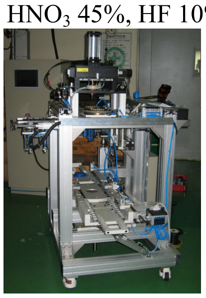

Fig 2. Photography of the multi-pin welding machine.

2.4 Investigation of the RW specimens

RW process depends on the heating effect of a current flow through an interface between an end plate and an end cap as shown in Fig. 1. The interface offers a resistance to the flow of a current, and the energy expended is converted to heat. Applying Ohm's law, the voltage(V) required for a current flow (I) is given by V=IR, where R is the resistance of the interface[2]. The heat energy for a current flow lasting t seconds is expressed as

$$H = IVt = I(IR)t = I^2Rt \text{ joules}$$

The heat (H) is concentrated into the joint area where the end plate and the end caps are brought into intimate contact as a result of a pressure applied by the main electrode. As the current continues to flow, the temperature rises until a melting occurs at the interface, forming a weld pool. If the current is now stopped, the joint area cools and a solidification takes place under pressure. The weld nuggets provide a bond between the end plate and the end caps which can transmit a load through a joint as shown in Fig. 3. The torque strength of a weld depends on the cross-sectional area of a nugget at the joint part. Fig. 4 shows the relationship between the pressure of the main electrode and the torque strength by using 5000A of a current. In the case of 80 psi of the pressure of the main electrode, the torque strengths of the outer rods were found to be about 7 Nm, which is smaller than that of the acceptable criteria (10-13 Nm). In order to obtain a clear understanding of a weld metal, an SEM examination was conducted on the a fracture surfaces of the node welded specimens. The node of fracture observed in the RW specimens was a ductile fracture with an entirely micro-void coalescence. The SEM fractography, as shown in Fig. 5, showed that the fracture takes place in the end plate around the periphery of the weld, leaving the nugget attached to the other end cap. The fracture morphology of the resistance welded specimens was very similar to that of the production test specimen, as a failure occurred in the weld zone.

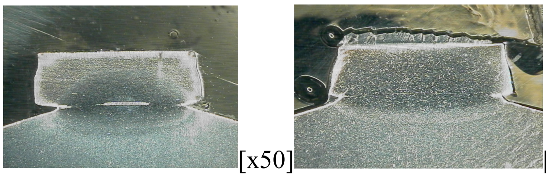

Fig. 3. Macro-sections of the experimental and production test specimens. [Left: 2cycles 5kA Right: 2cycles(KNFC)]

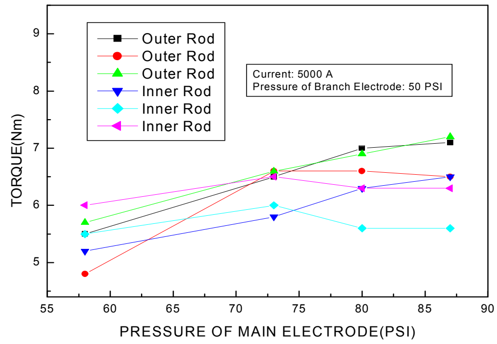

Fig. 4. Torque strength vs. weld current as location of inner rods.

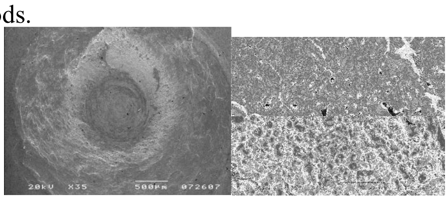

Fig. 5. Fractography of the torque test specimen. [Left: surface of facture(x35) Right: RW zone(x5000]

2.5 Investigation of the LBW specimens

In order to investigate the feasibility of a multi-pin remote welding between the end caps and the end plate by the LB spot method, an optical coupler by using a fiber transmission was applied as shown in Fig. 6. Fig. 7 shows the relationship between the number of specimens and the torque strengths by using LB spot welds. The results of the torque strengths were found to be about 3 to 4 Nm, which is smaller than that of acceptable criteria. From the above torque strengths, it was cincluded that LBW process is not suitable for the a multi-pin welding for DUPIC fuel fabrication.

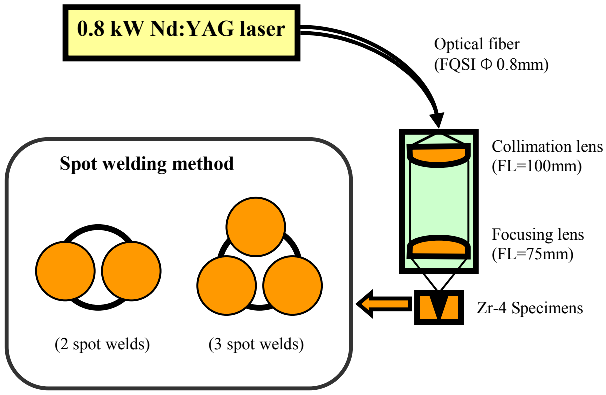

Fig. 6. Schematic illustration of the LB spot welding method.

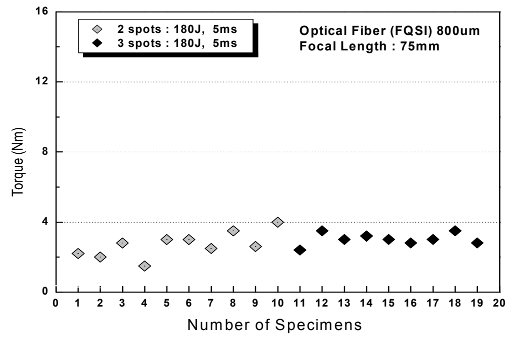

Fig. 7. Torque strength vs. number of LBW specimens.

3. Conclusion

This study was implemented to establish the Zr-4 multi-pin welding technology for a DUPIC fuel fabrication and to investigate the torque strength by means of a mechanical consideration. To establish the reliability of the RW specimens and the remote welding machine, it is necessary to carry out a performance test by using a manipulator in a mock-up facility. So, the optimum welding condition will be applied to the remote multi-pin welding process for a DUPIC fuel fabrication.

Acknowledgements

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REFERENCES

[1] J. D. Sullivan, "AECL's Progress in Developing the DUPIC Fuel Fabrication Process," *The 10th KAIF/KNS Annual Conference*, (1995).

[2] L. M. Gourd, "Principle of Welding Technology," *The Welding Institute,* pp.154-170 (1980).