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Investigation of Optimum Geometry of Bottom End Cap Welding Using Nd:YAG Laser (I)

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1. Introduction

Various welding processes are now available for end cap closure of nuclear fuel element such as gas tungsten arc welding (GTAW), magnetic resistance welding and Nd:YAG laser beam welding (LBW).[1][2] Even though the resistance and GTAW processes are widely used for manufacturing commercial fuel elements, they cannot be recommended for precise end cap welding of fuel elements due to the complexity of tungsten electrode alignment, wide heat-affected-zone (HAZ) and concave shapes and large heat input for thin cladding tubes. Therefore, Nd:YAG LBW using optical fiber transmission was selected for bottom end cap welding using HT9 alloy cladding tube. To establish LBW process, and satisfy the requirements of weld quality, preliminary experiments for optimizing welding conditions which had test specimens using bottom end cap to cladding tube were performed.

This paper describes the experimental results of the LB welded specimens using bottom end caps, along with the measurements of weld profiles and metallographic examinations. Furthermore, the effect of undercut depth and penetration depth after bottom end cap welding was also investigated by changing laser welding parameters and various dimensional configurations.

2. Materials and Results

2.1 Test Materials

The material used in this experiment was HT9 alloy. The chemical composition of test specimen is given in Table 1 and its schematic configuration, as shown in Fig. 1. These test specimens were prepared by LBW using bottom end cap and cladding tube. These test specimens were also ultrasonically cleaned in ethyl alcohol, and then dried.

2.2 Welding Machine

The welding machine was constructed using a pulsed-type Nd:YAG laser in order to achieve a circumferential welding. The laser welding system consists of an optical welding head, monitoring vision system, helium gas supply and rotary index. In this machine, the laser source for HT9 end cap welding also uses 500W of average power with optical fiber transmission.

2.3 Examination Procedure

Macro-sections of welded specimens were investigated through metallographic examination in order to determine undercut depth and penetration depth of the bottom end cap to the cladding tube. The laser welding conditions applied are summarized in Table 2. All welded specimens using bottom end cap to cladding tube were polished and etched electrically with the following etchant: 90% H_2O, and 10% oxalic acid (vol. %).

Table 1. Chemical composition of HT9 alloy in wt.%.

Alloy	C	Cr	Mo	Mn	V	W	Ni	Si	Fe
HT9	0.2	12	1.0	0.6	0.25	0.5	0.5	0.4	bal.

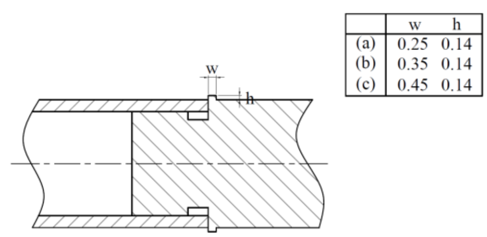


Fig 1. Configurations of bottom end cap to cladding tube specimen.

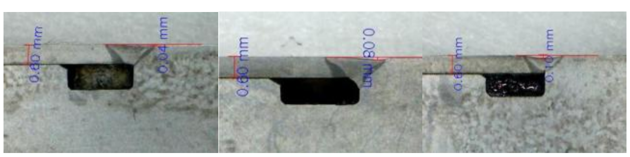
2.4 Investigation of optimum geometry for bottom end cap welding

It is evident that joint geometry of end cap to cladding tube has a significant effect on closure welding for fuel element fabrication. Some modification and improvement of joint geometry may be an advantage to autogenous welding process. If autogenous welding is solidified only in one direction during high density energy welding, modified and improved geometry can be fully melted by supplemental reinforcement. Due to having high density energy of laser beam, LBW generates a molten pool of material easier than arc welding process, and a deeper penetration depth can be obtained by laser beam.[3]

In order to conduct bottom end cap welding for fuel element fabrication, it is required that outer diameter of cladding tube after bottom end cap welding could be at least 9.5 mm and penetration depth could be more than 0.6 mm of cladding tube thickness. In the present experiment, the effect of undercut depth (UD) after bottom end cap welding was investigated by changing various configurations of bottom end caps and welding parameters. Fig. 2 shows typical appearances of LB welded specimens using w=0.25mm, w=0.35mm, w=0.45mm, and h=0.14 mm of bottom end caps, respectively as shown in Fig. 3. Fig. 4 and Fig. 5 show the relationship between undercut depth and penetration depth of bottom end cap welding using 800um optical fiber at focal length (FL)= 95 mm. In the case of w=0.25mm and h=0.14mm of bottom end caps, UD was found to be approximately 0.04 mm of average power 185 watt. In the case of w=0.35mm with a reinforcement part, UD was found to be 0.08 mm of average power 185 Watt, and in the case of w=0.45mm with a reinforcement part, UD was also found to be approximately 0.1 mm of average power 185 watt. As a result of examining the effect of UD measurements using various configurations of bottom end caps, it was found that suitable conditions of circumferential welding would be proper w=0.35mm and an average power of at least 185 watt to keep a min. 0.6mm of penetration depth.

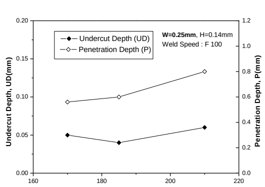
Table 2. Laser welding conditions for bottom end cap welding.

	Pre-weld	Main weld	Cosmetic
Average power (W)	23	185	6
Frequency (Hz)	8	8	8
Pulse width (ms)	2	11	1
Time (sec.)	5	13.7	5
Welding speed (F)	100	100	100



(a) (b) (c)

Fig. 2. Macro-cross sections of bottom end cap welded specimens using (a) w=0.25mm, (b) w=0.35mm and (c) w=0.45mm.



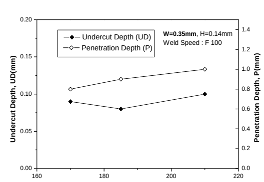


Fig. 3. Results of UD measurements using w=0.25mm.
Fig. 4. Results of UD measurements using w=0.35mm.

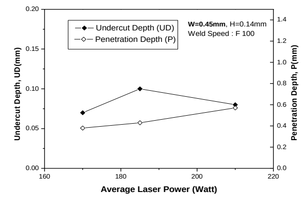


Fig. 5. Results of UD measurements using w=0.45mm.

3. Conclusion

This study was carried out to determine proper laser welding conditions and to select the optimum geometry joint for LBW using bottom end cap to cladding tube for fuel element fabrication. As a result of examining the characteristics of undercut depth measurements using various configurations of bottom end caps, it was found that suitable conditions of circumferential welding would be w=0.35mm, h=0.14mm and an average power of at least 185 Watt to keep a min. 0.6mm of penetration depth. Based on this fundamental experiment, fabrications of SFR fuel elements and assemblies will be provided at the Next Generation Research Reactor.

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