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Sturdy on Orbital TIG Welding Properties for Nuclear Fuel Test Rod

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1. Introduction

The centerline temperature, coolant temperature, rod inner pressure, and neutron flux resulting from the irradiation properties of nuclear fuels and materials are important factors for evaluating the nuclear fuel and material properties in pile. To analyse the irradiation characteristics of the new nuclear fuel developed in laboratory, nuclear fuel test rods must be fabricated with precise assembly and welding technologies [1-2]. Recently, we developed a precision TIG welding system that is able to weld the seam between end-caps and a fuel cladding tube for the nuclear fuel test rod and rig. This system can be mainly classified into an orbital TIG welder (AMI, M-207A) and a pressure chamber. The orbital TIG welder can be independently used, and it consists of a power supply unit, a microprocessor, water cooling unit, a gas supply unit and an orbital weld head. In this welder, the power supply unit mainly supplies GTAW power for a welding specimen and controls an arc starting of high frequency, supping of purge gas, arc rotation through the orbital TIG welding head, and automatic timing functions. In addition, the pressure chamber is used to make the welded surface of the cladding specimen clean with the inert gas filled inside the chamber [3]. To precisely weld the cladding tube, a welding process needs to establish a schedule program for an orbital TIG welding. Therefore, the weld tests were performed on a cladding tube and dummy rods under various conditions.

This paper describes not only test results on parameters of the purge gas flow rates and the chamber gas pressures for the orbital TIG welding, but also test results on the program establishment of an orbital TIG welding system to weld the fuel test rods.

2. Experimental

The welding specimens were conducted on the cladding tube and dummy rod of zircalloy-4, which is Zr-alloy containing minor additions of Sn in a solid-solution in a hexagonal close-packed phase (HCP) with minor additions of Fe, Cr, and/or Ni present in fine second phases [4]. The size of a cladding tube is 9.5mm in outer-diameter and 8.36mm in inner-diameter, and that of an end-cap is 9.5mm in outer-diameter, 8.1mm in inner-diameter, and 25mm in length. The chamber inside of the orbital TIG welding system is presented in Fig. 1. This pressure chamber is deigned and fabricated to weld the seam between an end cap and a cladding tube of the nuclear fuel test rod. The inside of the pressure chamber was mounted with sample holders and the orbital welding head.

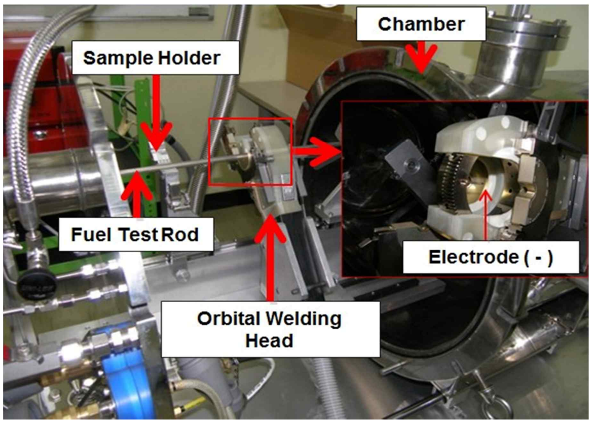

Fig. 1 Chamber inside of the orbital TIG welding system

All orbital TIG welding processes were automatically performed by the orbital TIG welding system programed according to the welding parameters, such as the currents, flow rates of the purge gas, gas pressures of the chamber, and travel speed of an electrode, as listed in Table 1.

Table 1 Parameters of the orbital TIG tests

Parameter	Condition
Currents	10~40 A
Regulator pressure	5bar
Flow rates of purge gas (Ar)	10~20 L/min
Purge time	50 sec
Gas (Ar) pressures of the chamber	1~2 bar
Travel speed of electrode	1.6 RPM
Weld times	10~30 sec
Electrode type	W-2% Tho.

The welding test to confirm the welding properties for the orbital TIG was carried out on the cladding specimens, and the establishment tests for the schedule program of an orbital TIG welding system was performed on the dummy rod seamed with an end-cap and a cladding tube.

3. Results and discussions

3.1 Effects of welding parameters

To analyze the effect of the orbital TIG welding, various welding tests were carried out with the cladding specimens. The results with 10-20 L/min PGFR (Purge Gas Flow Rate) in 1-2 bar CGP (Chamber Gas Pressure) at a current of 10A are shown in Table 2. The width of HAZ (Heat Affect Zone) of a cladding specimen surface welded at the identical power during an orbital TIG welding schedule was continuously increased from a welded start-point to a welded end-point because of heat accumulation. The welding effect of the CGP in the identical PGFR has a relatively large difference for FSS (first spot size) but that of the PGFR in the identical CGP has a relatively small difference. The welding effect of the PGFR and CGP shows a relatively large difference for LSS (last spot size).

Table 2 Results of the orbital welding test for the cladding specimens

PGFR (L/min)	CGP (bar)	FSS (mm)	LSS (mm)
10	1	0.40	1.34
20	1	0.37	1.08
10	2	0.58	1.19
20	2	0.60	1.10

The cladding specimens welded at a current of 20A with welding conditions of PGFR and CGP are shown in Fig. 2. Their surface HAZs can be classified with a welding start point, a welding route and a welding end point formed by the arc of the orbital TIG welder.

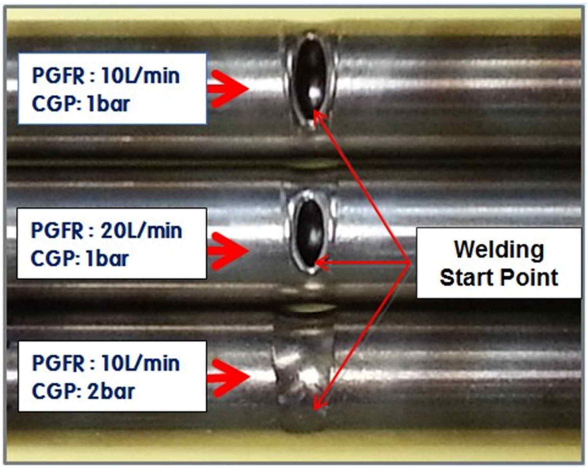

Fig. 2 Surfaces of cladding tubes welded at 20 A with welding conditions of PGFR and CGP

Each hole was formed on the cladding specimens welded with the PGFR of 10L/min and 20L/min in the CGP of 1bar, and the size a hole made with the PGFR of 10L/min is larger than that with the PGFR of 20L/min. However, it was not shown in the case of the PGFR of 10L/min in the CGP of 2bar. This phenomenon is considered due to the cooling effect by flowing argon gas and the pressure effect by the difference between the PGFR and CFG. The cooling effect is caused by the gas amount supplied during the orbital TIG welding process and the CGP filled up gas. The pressure effect results in the pressure difference between the CGP and PGFR being initially high, but increasing the pressure of a chamber filled up with gas during the welding process, the pressure of the PGFR is lower than the initial gas pressure. Therefore, the hole in the high CGP of 2bar was not formed in a cladding tube, but that in the low CGP of 2bar was formed.

3.2 Program establishment

The program establishment test was performed on a dummy rod seamed with an end-cap and a cladding tube to obtain the optimum schedule program of an orbital TIG welding system for the nuclear fuel test rod. The schedule program established through experiments for the orbital TIG welding is shown in Table 3. It was divided by four levels that consist of time, current and RPM to obtain a uniform weld property, and continuously implemented to each level to weld a cladding specimen. In this program, the weld current supplied with the fuel rod was regularly reduced from 40A to 31A to prevent a cladding tube from accumulating heat.

Table 3 a schedule program established for the orbital TIG welding

Levels of program	Times (sec)	Currents (A)	RPM
1	12	40	1.6
2	12	37	1.6
3	12	34	1.6
4	12	31	1.6

The soundness of the fuel rod specimen welded by the schedule program was confirmed by microstructural analyses.

4. Conclusions

Various welding tests were performed to develop the orbital TIG welding techniques for the nuclear fuel test rod. The width of HAZ of a cladding specimen welded with the identical power during an orbital TIG welding cycle was continuously increased from a welded start-point to a weld end-point because of heat accumulation. The welding effect of the PGFR and CGP shows a relatively large difference for FSS and LSS. Each hole on the cladding specimens was formed in the 1bar CGP with the 20L/min PGFR but not made in the case of the PGFR of 10L/min in the CGP of 2bar. The optimum schedule program of the orbital TIG welding system to weld the nuclear fuel test rod was established through the program establishment test. The soundness of the fuel rod specimen welded by the schedule program was confirmed through microstructural analyses.

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