Quality Control Parameters for Automatic Welding of Radioactive Material Containers

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INTRODUCTION

More than 30 commercial nuclear reactors are operating at present in Japan and a lot of spent nuclear fuels (hereafter called "spent fuel") are generated from these nuclear reactors. After they have been temporarily stored at the storage pool within the nuclear power plant, these spent fuels are scheduled to be disposed of at a reprocessing plant in England or France, or at the domestic reprocessing plant planned for Shimokita.

The residues generated when the spent fuel is subjected to reprocessing are scheduled to be solidified within stainless steel (SUH309) glass solidifying containers (canisters), shown in Fig. 1, and stored for several dozen years before disposal. Plasma arc welding using automatic remote operation is used to secure the canister cover ; however, the oxidated scale or oil/grease which may adhere to the base material surface at the canister weld may adversely influence the welding when the molten glass is poured in the canister. However, it is difficult to perform a general non-destructive examination of the weld, and it is not possible to fully confirm the weld for soundness as the glass-solidified residue generates extremely high radioactivity. Consequently, strict quality control is required when performing the automatic remote welding.

In this study, the stainless steel plate was fillet-welded and butt-welded to make a test weld and simulation of the canister flange. The weld was subjected to various examinations to evaluate the welding current, welding speed, surface condition of base material, and other conditions essential to sound welding from the view point of quality control.

SETTING OF WELDING CONDITIONS

Prior to welding the test piece and simulation canister flange, a preliminary test was conducted by the use of SUS304L plate to set the welding current and welding speed. The shape of the plate used for the preliminary test is shown in Fig. 2.
The welding was executed by using the plasma arc method without supplying the filler material to find the welding current/welding speed range which was thought proper.

The results of the above test are shown in Fig. 3. According to Fig. 3, the welding c urrent of approx. 80A is thought to be proper when the filling material is not supplied.

As to the welding speed, satisfactory welding could be assured at a welding speed of 80 ~ 130mm/min.; however, it was set at 130 ~ 140mm/min. for the welding of the canister flange simulation body because the bead at the former range was too wide.

FILLET WELDING/BUTT WELDING TEST

Test of Fillet Welding

The SUH309 plate with a thickness of 3mm and 5mm was subjected to fillet welding by plasma arc welding as shown in Fig. 4 in accordance with the welding condition shown in Table 1 and subjected to a visual inspection test after welding.

The resulting summary of the test result is shown in Table−2.
Considering the possibility that an oil/grease compound, such as used lubrication oil, adhere to the canister when the molten glass is poured in the canister, oil is applied to test pieces 3−A, 5−A, and 5−B. After the test pieces are lightly wiped off with a cloth, they are welded. On the other hand, test pieces 6−A and 6−B are those prepared by heating the base material to 800℃ for the generation of oxidated scale on the surface t o simulate the oxidated scale which may be generated on the canister surface when the molten glass is poured in the canister. As shown in Table−2, the test pieces covered with oil provide an un−stabilized bead, as the oil is boiled at some point or other. However, the test pieces heated to 800℃ assure a satisfactory bead. Test pieces 2−A, 2−B, 6−A, and 6−B proved to be safisfactory as they exhibited stabilized bead width, no undercut, and a rather smooth bead surface.

Test of Butt Welding

The test piece prepared by butt welding is shown in Fig. 5 It was produced from SUH309 by plasma arc welding in the same manner as the fillet welding test pieces were produced. The welding condition for the test piece is as shown in Table−3. The bending test and joint tensile test were conducted to test the weld.
In addition, the weld was measured for hardness.
The resulting measurement is shown below.

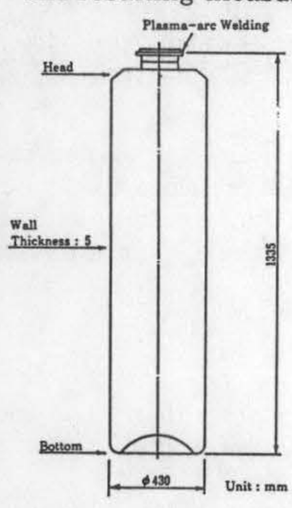

Fig. 1 Canister for Vitrified Waste Package

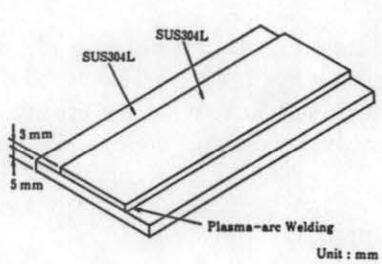

Fig 2 Plate for Pre−test

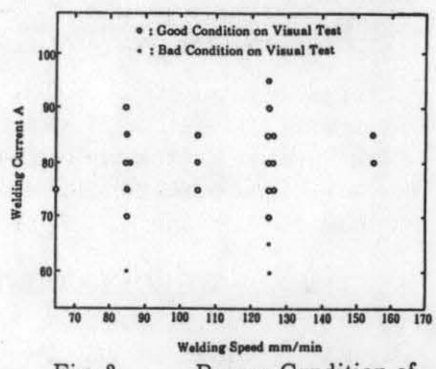

Fig. 3 Proper Condition of Welding Current and Speed

Table 1 Conditions of Fillet Welding

Test No.		②, ③, ⑥	①, ④, ⑤
Welding Method		PAW-auto	PAW-auto
Angle of Torch		45°	45°
Filler		Not Used	TGS-310HSA (ϕ1.2mm)
Feeding Speed	mm/min	–	200
Shield Gas		Ar	Ar
Oriffice Gas		$Ar+H_2$	$Ar+H_2$
Flow Rate of Shild Gas	l/min	20	20
Flow Rate of Orifice Gas	l/min	Ar:1 H_2:0. 5	Ar:1 H_2:0. 5
Welding Current	A	80～85	100
Welding Speed	mm/min	130～140	130～140

1) Bending test

Root bending and face bending were used for the bending test at a bending radius of 6mm (2t).

Both test pieces 7 and 8 remained sound without any crack.

2) Tensile test of joint

The result of the joint tensile test is shown in Table−4. Test piece 7 and 8 broke at the weld. The tensile strength exceeds the specified value of 57kgf/cm However, test piece 8 to which filling was supplied showed a decreased tensile strength as compared with test piece 7 to which no filling material was applied. However, the latter provided a high carbon content as shown in Table−5 and a slightly higher hardness as shown in Fig. 6.

3) Measurement of hardness

The hardness measured at the weld and on both sides is shown in Fig. 6.

The base material on both sides of the weld was not subjected to heat tre atment but remained as rolled. Therefore, it had a Vicker's hardness of approx. 320. The hardness quickly decreased from the base material toward heat−affected zone, and the Vicker's hardness at the welded metal part was 150 ~ 160. A similar tendency was observed for test pieces 7 and 8.

Table 2　Visual Test Results(Fillet Welding)

Test No.	Test Conditions			Appearanco of Welding Bead
	Filler		Cleaning	
	1 st	2 st		
1−A	Not Used	Used	Clean (Acetone)	Convex
1−B	〃	〃	〃	〃
2−A	Not Used	−	Clean (Acetone)	Good
2−B	〃	−	〃	〃
3−A	Not Used	−	Smeary	Unstable
3−B	〃	−	〃	Pit
4−A	Used	−	Clean (Acetone)	Convex Unstable
4−B	〃	−	〃	〃
5−A	Used	−	Smeary	〃
5−B	〃	−	〃	〃
6−A	Not Used	−	Oxidized Scale	Good
6−B	〃	−	〃	Good

Table 3　Conditions Butt Welding

Test No.		①	②
Welding Method		PAW-auto	PAW-auto
Position		Flat	Flat
Filler		−	TGS-310HSA (ϕ1.2mm)
Feeding Speed	mm/min	−	200
Shield Gas		Ar	Ar
Oriffice Gas		Ar+H_2	Ar+H_2
Flow Rate of Shild Gas	l/min	20	20
Flow Rate of Orifice Gas	l/min	Ar:1 H_2:0.5	Ar:1 H_2:0.5
Welding Current	A	85	90
Welding Speed	mm/min	130	130
Number of Layer		1	1

TEST OF CANISTER FLANGE SIMULATION MODEL

Production of Simulation Model

The shape of the canister flange simulation body is shown in Fig. 7. Plasma arc welding was used to weld the cover to the flange. The welding posture taken in this case is shown in Fig. 8. The use or non−use of filling material and the surface condition of the base material are as shown in Table−6. Since the temperature of the flange when the lid was welded after pouring molten glass into the canister at the retreatment plant was approx. 120 ℃, the temperature of the flange before welding was also set at approx. 120℃ when welding the simulation body.

Table4 Tension Test Results for Butt Welded Joint

Test No.	Tensile Strength Kgf/mm	Location of Fracture
⑦ (Non-filler)	62.6 62.6	Weld Metal 〃
⑧ (Filler)	60.0 58.1	〃 〃
Criteria	≦57	———

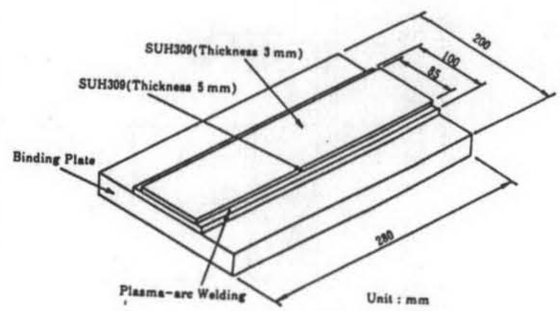

Fig. 4 Test Piece Produced by Fillet Welding

Table 5 Results Chemical Analysis of Weld Metal

Test No.	Chemical Composition %					
	C	Si	Mn	P	S	Ni
⑦	0.13	0.68	1.40	0.006	0.0056	13.05
⑧	0.17	0.64	1.27	0.005	0.0048	14.77
JIS G 4312 SUH309	≦0.20	≦1.00	≦2.00	≦0.040	≦0.030	12.00 ~15.00

Test No.	Chemical Composition %					
	Cr	Ti	Nb	—	—	—
⑦	22.37	—	—			
⑧	22.73	0.014	0.093			
JIS G 4312 SUH309	22.00 ~24.00	—	—			

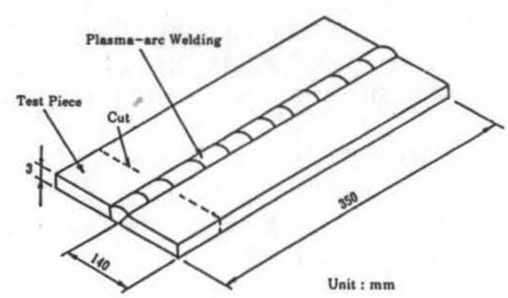

Fig. 5 Test Piece Produced by Butt Welding

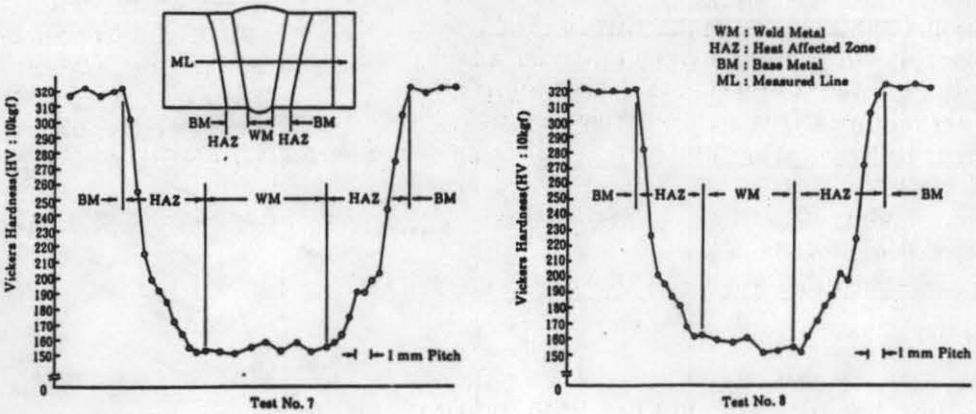

Fig. 6 Results of Hardness Test

TEST

The appearance inspection, radiographic test and dye penetrant test were performed on the weld bead between the lid and flange.
A helium leak test and peel test were also performed thereafter.
In this test, the leak test plug and pipe were fitted to the underside of the carbon steel restriction plate by fixing the canister flange simulation plate by tig welding. To test the weld for containment soundness, helium gas was pumped into the internal space, as shown in Fig. 9(a), to measure the helium gas leak through the plasmaarc weld between the lid and flange by using a helium leak detector.

In the peel test, on the other hand, the canister flange simulation body was placed in such a manner that the flange was supported on the restriction ring, and the flange was applied from the inside of the lid at a constant speed (3. 5mm/min.) until the weld at the lid or between the lid and flange was raptured.

TEST RESULT

The summary of the test conducted against the simulation models of the canister flange is shown in Table-6.

For the visual inspection and radiographic test, a satisfactory result was achieved except for simulation models (1) and (3) .
The bead shape of simulation models (3) is thought to be unstable as the base material at the weld was coated with oil/grease and such oil/grease is boiled at some point or other.

A pin hole with a diameter of approx. 0. 5mm was found in simulation models (4) and (5) during the liquid penetrant flaw test. However, the defect was not as remarkable as in (1) and (3) , and a sound result was observed except for simulation models (1) and (3) .
In the case of the helium leak test, simulation model (3) , of which the base material surface was coated with oil/grease, revealed the greatest leak or 6.28×10^{-6} atm • cc/s, and all other simulation models provided a leak of approx. 2.2×10^{-8} ~ 2.6×10^{-8} atm • cc/s.

In the peel test, the center of the lid was cracked for simulation models (1) , (4) and (5) , and simulation models (2) , (3) and (6) were raptured at the weld.
This was probably because the throat thickness was increased in simulation models (1) and (4) due to the filling material and decreased in simulation models (2) , (3) and (4) due to the contrary condition.
Simulation model (5) was prepared by adhering oil/grease to the base material.
However, it provided a satiafactory result in each test as the filling material increased the weld metal.
Simulation model (6) was prepared by heating it to 800℃ prior to welding to generate an oxidated scale on the surface.
The test piece provided a satisfactory result in each test.

CONCLUSION

The following results were obtained tests by using test pieces and a simulation of the canister flange made by the plasma arc welding method of fillet welding and butt welding.

1) When oil/grease adheres to the canister flange, it is difficult to execute a sound weld. However, a sound weld is probable when filling material is applied. Nevertheless, from the point of view of quality control, it is necessary to prevent oil/grease from adhering to the flange.
2) Oxidated slace generated when the glass is poured in the canister will not affect the welding.
3) When welding thin plates (thickness of approx. 3mm) by the plasma arc welding method, it is possible to execute sufficient containment welding without the use of filling material.
4) Tack welds should be used to prevent the lid from lifting due to heat deformation.

It was proved that sound containment welding could be expected from automatic remote operation as long as the adhesion of oil/grease to the weld is prevented by quality inspection of the canister lid and the welding conditions are properly as controlled.

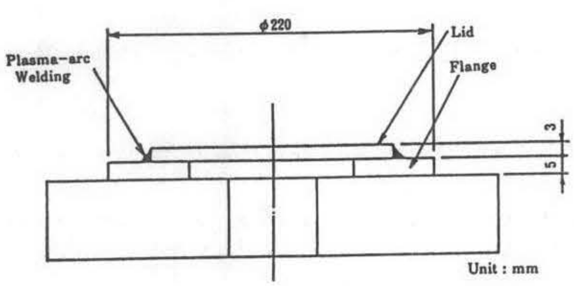

Fig. 7 Test Flange of Canister

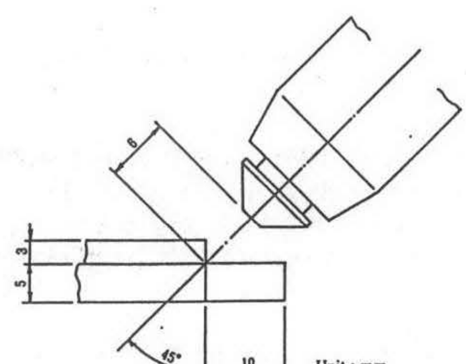

Fig. 8 Welding Position of Test Frange

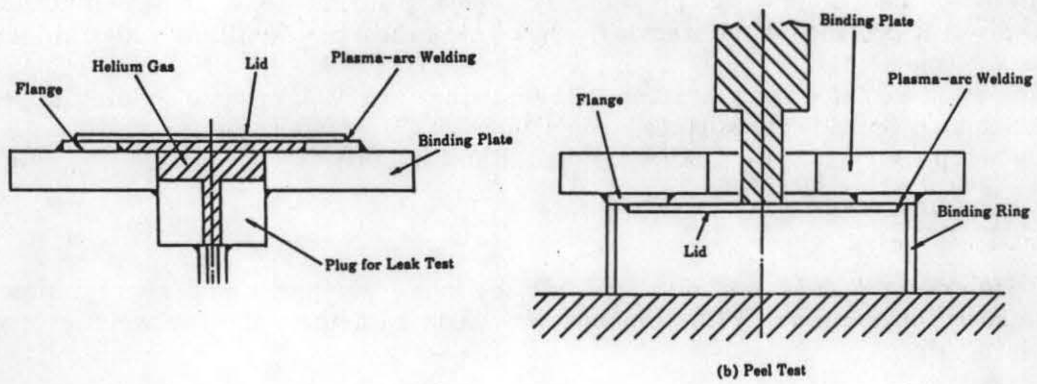

Fig. 9 Summaries of Helium Leak and Peel Tests

Table 6 Welding Conditions and Test Results Test Flange

	①	②	③	④	⑤	⑥
Conditions						
oFiller	1st Used 2nd Not Used	Not Used	Not Used	Used	Used	Not Used Oxidized
o Cleaning	Clean	Clean	Smeary	Clean	Smeary	Scale
Results						
oVisual Test	Undercut	Good	Concave Undercut	Good	Good	Good
oRadiographic Test	3Defects	Good	Concave	Good	Good	Good
oPenetrant Test	Undercut	Good	Concave Undercut	1 Pinhole	1 Pinhole	1 Pinhole
oLeak Test (Leaktightness atm · cc/s)	2.53×10^{-8}	2.43×10^{-8}	6.28×10^{-8}	2.30×10^{-8}	2.26×10^{-8}	2.22×10^{-8}
oPeel Test(Load ton) (Location of Fracture)	16.9 Lid Center	15.9 Weld Bead	14.3 Weld Bead	16.3 Lid Center	18.2 Lid Center	14.0 Weld Bead