Effect of Welding Processes on Corrosion Resistance of UNS S31803 Duplex Stainless Steel

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An attractive combination of corrosion resistance and mechanical properties in the temperature range -50 to 250°C is offered by duplex stainless steel. However, undesirable secondary precipitation phase such as σ, γ_2 and Cr_2N may taken place at the cooling stage from the welding processes. Therefore, this paper describes the influence of different welding procedures such as manual metal arc welding (MMA), tungsten inert gas welding (TIG) and vacuum brazing on corrosion resistance of the welded joint for UNS S31803 duplex stainless steel. Microstructure and chemical compositions of the welded joint were examined. The weight loss of specimens immersed in 6% $FeCl_3$ solution at 47.5°C for 24-hours was determined and used to evaluate the pitting resistance of duplex stainless steel and their welds. The region of heat-affected zone of specimen obtained by the MMA is much wider than that resulted from TIG, therefore, the weight loss of welds by MMA was larger than that of weld by TIG. The weight loss of brazed specimens cooled from slow cooling rate was larger than those of specimens cooled from high cooling rate, because the precipitation of σ phase. Beside that, the weight loss of brazed specimen is greater than those of the welded specimens. The galvanic corrosion was observed in brazed duplex stainless steel joints in the chloride solution.

Keywords : duplex stainless steel, welding, brazing, immersion testing

1. Introduction

Duplex stainless steel (DSS) combines the favorable properties of ferrite and austenite, which are present in approximately equal amounts. In the latest one or two decades, it was studied to be approved that the duplex stainless steel not only the full mechanical properties, corrosion resistance and weldibility better than austenitic systemic stainless steel but lower cost, especially extremely fitted in the environment containing chloride, so we take it as the upgrade material of austenitic systemic stainless steel.[1-2]

Much attention has over the years been focused on the welding aspects of highly alloyed stainless steels. It is therefore vital that welds can be produced with properties matching those of the base material as closely as possible.[3-6] However, undesirable secondary precipitation phase such as σ, γ_2 and Cr_2N and associated brittleness may taken place at the cooling stage from the welding processes. It was virtually impossible to avoid undesirable precipitation in the heat affected zone when welding duplex stainless steel and as a result, a weld with low toughness and low corrosion resistance was produced. In recent years the role of nitrogen has been discovered. Nitrogen is a very potent austenite stabilizer and optimizing of the α / γ ratio and alloying with nitrogen have made the weldability of the DSS of today equal to that of the austenitic stainless steels.[7-8]

The processing parameters of the vacuum brazing included temperature, degree of vacuum, cooling rate can suitably be controlled. When the specimens were heated into the high temperature, the temperature distribution in the brazed joint was uniform. The heat-affected zone was not observed in the brazed joint under different cooling schedules[10] Therefore, this paper describes the influence of different welding procedures such as manual metal arc welding (MMA), tungsten inert gas welding (TIG) and vacuum brazing on corrosion resistance of the welded joint for SAF 2205(UNS 31803) duplex stainless steel.

2. Experimental

The chemical compositions of a SAF 2205 duplex stainless steel, supplied by the Sandvick Co., are shown in Table 1. The 2205 stainless steel plates were cut into the brazed specimen in 100 mm × 50 mm × 7.5 mm. The

Table 1. Chemical composition of SAF 2205 steel and different fillers (wt%)

	C	Mn	P	B	Si	Ni	Cr	Mo	N	Cu	PRE$_N$
2205 DSS	0.02	1.80	0.02	--	0.85	5.53	22.0	3.0	0.14	--	34.1
Sandvik 22.9.3.LR	0.016	0.65	0.016	--	0.83	9.0	22.6	3.2	0.16	0.0	35.7
Sandvik 22.8.3.L	0.03	1	0.02	--	0.6	9	23	3.2	0.17	0.1	36.3
BNi-3	0.06	--	0.02	3.13	4.5	Bal	--	--	--	--	--
BNi-7	0.08	--	10.1	--	0.1	Bal	14.0	--	--	--	--
Cu Foil	--	--	--	--	--	0.2	--	--	--	Bal	--

Table 2. Welding conditions for manual metal arc welding

Welding material		Pass/ Layer No.	Preheat/ Interpass Temperature	Current (A)	Voltage (V)	Speed (cm/min)	Heat Input (kJ/mm)
Filler metal	Wire (mm)						
Sandvik 22.9.3.LR	ø 3.25	1	100°C	100	32	12.7	1.51
		2	120°C	101	30	12.4	1.47
		3	145°C	100	30	12.3	1.47

Table 3. Welding conditions for tungsten inert gas welding

Welding material		Pass/ Layer No.	Preheat/ Interpass Temperature	Current (A)	Voltage (V)	Speed (cm/min)	Heat Input (kJ/mm)
Filler metal	Wire (mm)						
Sandvik 22.8.3.L	ø 2.4	1	100°C	100	21	8.8	1.43
		2	115°C	101	20	8.4	1.58
		3	140°C	100	22	8.3	1.59
		4	145°C	102	21	8.2	1.57

chemical compositions of the nickel-based alloy powders (BNi-3 and BNi-7) and copper foil, chosen as brazing filler, are also showed in Table 1.

The welding consumables and the welding parameters of the manual metal arc welding are summarized in Table 2. Meanwhile, the welding consumables and the welding parameters of the tungsten inert gas welding are summarized in Table 3. Different shielding and backing gas under selected nitrogen volume fraction in 0%, 2.5%, 5% and 10% was performed in TIG welding.

Nickel-based filler in the form of atomized powders was mixed with the Nicrobraze S-binder in the ratio of 3:1 to form a paste, and used in the vacuum brazing. The fixture made by SUS304 stainless steel was used to furnish the vacuum brazing. The brazing pairs were placed in the vacuum furnace and heated to temperatures above the melting temperature of the filler at an appropriate rate. After holding the specimen at the brazing temperature for

10 minutes, it was cooled down in different rates.

Metallurgical specimens, cut from the different welded joint, were grounded, polished and etched. Microstructures were conducted in an optical microscopy in the BH2-UMA type produced by Olympus Co. The line profile of element concentration was conducted by an electron probe x-ray micro-analyzer (EPMA) in a JxA-8600sx type.

The corrosion tests were conducted by immersing the samples in a 6% FeCl$_3$ solution kept at 47.5°C for the time duration of 24 hours. The weight loss of the corroded sample was measured by using an ER-182A electronic balancer. The morphologies of corroded surface were obtained by a scanning electron microscopy (SEM) in the JEOL JSM-5600 type, made in Japan.

3. Results and discussion

3.1 Microstructure analysis

The microstructures of welding zones of specimens joined by (a) TIG and (b) MMA are shown in Fig. 1. Both series of specimens, TIG and MMA, revealed the usual welding zone observed in DSS, i.e. the melting zone and the heat affected zone, the latter subdivided into the overheated and partial annealed zone. As can be seen in

Fig. 1. Air-cooled Weld. Welding zone (left to right): Partial annealing, overheating, melting zone produced by the (a) TIG and (b) MMA.

Fig. 2. The microstructures of vacuum brazed joints for SAF 2205 DSS brazed at 1090°C and cooled at 0.1°C/s under 10-5 torr by using the copper filler.

the figure, the region of heat-affected zone of specimen by the MMA is much wider than that resulted from TIG. The ratio of ferrite and austenite were varied in the heat-affected zone, therefore, the corrosion behavior was also changed.

The microstructure of specimen etched by the solution contained 10 ml HNO_3, 20ml HCl and 30ml water was used to reveal the interface. Fig. 2 illustrated the microstructure of the vacuum brazed joint for SAF 2205 DSS brazed at 1090°C for 10 minutes and cooled to room temperature in the rate of 0.1°C/s under the vacuum of 10^{-5} Torr by using the copper filler. The filler layer combined with the obvious transition layer is shown in the Fig. 2; that is, a concentration gradient was formed in these brazed joints.

The SEI and the elemental distribution of copper in a brazed joint with copper filler were shown in Fig. 3. The line profile of copper was demonstrated a gradually decreasing tendency in the transition layer. The mapping of copper also shown the same result; however, the diffusion of the copper atom into the duplex stainless steel was not apparent.

Fig. 3. Secondary electron image (SEI) and elemental distribution of a joint brazing with SAF 2205 stainless steel with copper filler (a) line profile of copper and (b) copper mapping.

Table 4. Weight loss of SAF 2205 duplex phases stainless steel

Specimen	Area (mm^2)	Weight (g); Before corrosion	Weight (g); After corrosion	Loss (mg/mm^2)	Remark
Base material SAF 2205	683.15	8.6567	8.6343	0.0328	Sandvik received
MMA	537.88	5.7444	5.7067	0.0701	Filler: Sandvik 22.9.3. LR
TIG (Shielding gas: 100% Ar)	750.84	8.7062	8.6734	0.0437	Filler: Sandvik 22.8.3. L

3.2 Corrosion behavior

Assessment of pitting corrosion resistance of stainless steels is frequently made by the immersion testing in ferric chloride solution.[11] In this report, the weight loss of specimens immersed in 6% $FeCl_3$ solution at 47.5°C for 24-hours was determined and used to evaluate the pitting resistance of duplex stainless steel and their welds. The
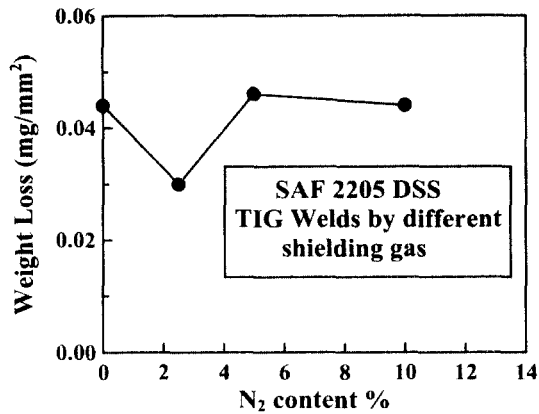
Fig. 4. Weight loss of welded joints by TIG as a function of N₂ condition shielding gas.

Fig. 5. Weight loss of parent metal and vacuum brazed joints using BNi7 and copper filler in different cooling rate

weight loss of SAF 2205 base metal and some welds was shown in Table 4. According to the influence of the heat-affected zone and weld pool, the weight loss of welded specimens is larger than those of base metal. As in the preceding section, the heat-affected zone of welds by MMA was larger than that of welds by TIG, therefore, the weight loss of welds by MMA was larger than that of weld by TIG.

Fig. 4. shows the weight loss of welded joint by TIG as function of nitrogen content in the shielding gas. As can be seen in the figure, the weight loss of specimen welded by TIG in a shielding gas at a atmosphere of 98% Ar + 2% N₂ is lowest among all studied specimens.

The weight loss of vacuum brazed joints on given conditions after immersed test as shown in Fig. 5. It is obvious that the weight loss of specimens cooled at a rate of 0.85°C/s is smaller than those of specimens cooled at rate of 0.1°C/s. According to the research of Potgieter,[11] σ phase was a harmful phase the corrosion resistance of duplex stainless steel. When the σ phase contained in duplex stainless steel was increased, the pitting resistance of duplex stainless steel was decreased. Therefore, the weight loss of specimen cooled from slow cooling rate was larger than those of duplex stainless steel. Under the same cooling rate, the weight loss of vacuum brazed joints is larger than those of base metal in immersion tests. This is clear that the weight loss of brazed and welded joint is greater than those of parent metal.

Some typical surface morphology of corroded specimens after immersion testing is shown in Fig. 6. It is difficult to distinguish parent metal and welding pool, because the welding pool almost do not be corroded. Only few pits were observed in the immersed TIG welded samples even in the welded zone as shown in Fig. 6(a). For the sake of the galvanic series between copper and
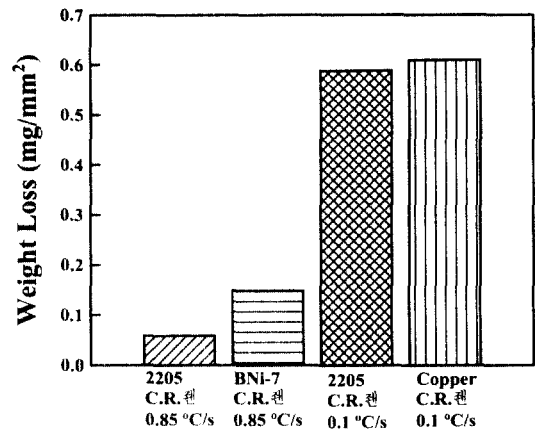
duplex stainless steel, the copper filler and its neighboring reaction region of copper-brayed joint was preferentially corroded (Fig. 6(b)). Fig. 6(c) also shows the localized corrosion in the filler of BNi-3 brazed joints. In the Fig. 6(d), the obvious corroded region was occurred in the reacted zone, meanwhile, the BNi-7 filler are survived after immersion test. The galvanic corrosion was also observed in brazed duplex stainless steel joints using three fillers such as the BNi-3, BNi-7 and copper foil and welding metal in the chloride solution. If the galvanic cell was established, the obvious corrosion was taken place in the brazed joint, especially in interface of two steel plates. Consequently, the type of filler used to braze the duplex stainless steel must carefully be chosen to decrease the difference of galvanic series.

4. Conclusions

1) The region of heat-affected zone of specimen obtained by the MMA is much wider than that resulted from TIG, therefore, the weight loss of welds by MMA was larger than that of weld by TIG.

2) The weight loss of brazed specimens cooled from slow cooling rate was larger than those of specimens cooled from high cooling rate, because the precipitation of σ phase. Beside that, the weight loss of brazed specimen is greater than those of the welded specimens.

3) The galvanic corrosion was observed in brazed duplex stainless steel joints in the chloride solution. Consequently, the type of filler used to braze the duplex stainless steel must carefully be chosen to decrease the difference of galvanic series.

Fig. 6. The SEM morphologies of corroded specimens that immersed in 6% $FeCl_3$ solution at 47.5°C for 24 hours in given condition (a) TIG welding, shielding gas: 90% Ar + 10% N_2 (b) Brazing filler: copper, cooling rate: 0.1°C/s (c) Brazing filler: BNi3, cooling rate: 0.1°C/s (d) Brazing filler: BNi7, cooling rate: 0.85°C/s

Acknowledgements

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