Weldability of Type 444 Ferritic Stainless Steel GTA Welds

C. Li and H. S. Jeong

Abstract

The ferritic stainless steels are generally considered to have poor weldability compared with that of the austenitic stainless steels. However, the primary advantages of ferritic stainless steels include lower material cost than the more commonly used austenitic stainless steels and a greater resistance to stress corrosion cracking. Thus, the weldability of ferritic stainless steels was investigated in this study. In concerning the weldability, Grain size measurement test, Erichsen test and Varestraint test were involved. Full penetration welds were produced by autogeneous direct current straight polarity (DCSP) and pulsed currents gas tungsten arc welding (GTAW) and the effect of pulsed currents welding on the welds was compared to that of DCSP welding. The results showed that pulsed current was effective to refine grain size in the weld metal and the finest grain size was obtained at the frequency of 150Hz. In addition, the ductility of welds was lower than that of base metal. Finally, autogeneous type 444 welds were less susceptible to macro solidification cracks, but more sensitive to micro cracks; SEM/EDS analysis indicated that all the inclusions in the crack showed enrichment of Mn, Si, O and S.

Key Words : Ferritic stainless steel, Pulsed current GTAW, Grain size, Varestraint test, Erichsen test.

1. Introduction

In considering the weldability of a steel, several types of cracking need to be avoided, several welding processes may be involved, various weldment properties need to be achieved and the restraint and thickness of the metals under consideration may vary considerably[1].

When welding ferritic stainless steels, one of the most important problems is the grain coarsening of weld metal. The heat of welding leads to grain coarsening in the HAZ and in the weld metal of ferritic stainless steels because they solidify directly from the liquid to the ferrite phase without any intermediate phase transformation[2]. In the meantime, the choice of stabilizing element has been shown by Sawhill and Bond to strongly affect the weld microstructure of 18Cr-2Mo stainless steels[3].

Weldability of steels is largely determined by their susceptibility to cracking either in the weld or in the HAZ[1]. Weld and HAZ hot cracking in the ferritic stainless steel is not as common a problem as with austenitic stainless steels[4]. This is a result of the lower coefficient of thermal expansion (CTE) of the ferritic stainless steels, and the greater solubility of sulfur and phosphorus in ferrite. However, excessive amounts of stabilizing elements have been shown to cause hot cracking as well as reduced ductility[5].

2. Experiment procedure

Ferritic stainless steels are also susceptible to embrittlement (loss of toughness and/ or ductility) as a result of welding[6]. In view of welding type 444, grain growth in the weld meal and in the HAZ will be even more exaggerated[7] and ductility will again be decreased. Thus, the weldability of type 444 inevitably requires greater understanding of the mechanical properties such as ductility.

The chemical compositions of type 444 are shown in Table 1. Specimens were prepared as square with dimensions of 200×80×1.5 mm^3. Full penetration welds were produced with autogeous gas tungsten arc welding (GTAW). Welds were made by direct current straight polarity (DCSP) and pulsed current GTAW following the

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Table 1 Chemical compositions of type 444 stainless steel

Material	Element (wt%)									
Type 444	C	Si	Mn	P	S	Ni	Cr	Mo	N	NB
	0.01	0.24	0.167	0.034	0.017	0.143	18.39	1.877	0.01	0.4533

Fig. 1 Weld microstructures of type 444 stainless steels welds. Magnification: ×100; Etchant: 10% oxalic acid

conditions listed in Table 2. In the case of pulsed current welding, the ratio of pulse time and background time was kept constant, but the pulse frequency was varied. After welding, the specimens were sectioned, ground, mounted, polished and etched, optical microscopy being used to examine the weld microstructure. All the specimens responded well to an electrolytic reagent using 10% oxalic acid in distilled water at 6V for times up to 3 minutes. Grain size measurements were performed by width of individual grain (WIG) with a quantitative image analysis.

Table 2 Welding procedures

Shielding gas:	100% Ar
Gas flow:	15ℓ/min
Tip clearance:	2mm
Voltage:	12V
Arc current:	120A, 90A
Travel speed:	50, 30 cm min^{-1}
Polarity:	DCSP, d.c. pulsing
Pulse frequency:	30, 100, 150 and 200Hz
Base current:	25A
Heat input:	1728, 2160 J/cm

Varestraint tests were conducted over an applied strain range of 0.19% to 3.03%. Sixty Varestraint specimens of 130mm length × 25 mm width were prepared from the 2.4 mm thick sheet for autogeneous weldability evaluation. The GTAW process was used with the following currents and travel speeds: 130A to 175A, 35cpm; 170A to 200A, 42cpm. The other welding procedures were identical to those presented in Table 2.

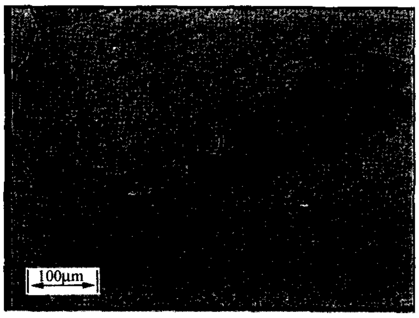
For measuring the ductility, Erichsen test was conducted according to KS B 0812. In this test, a 25.4 mm ball was raised at the rate of 20 mm/min, and it was determined by measuring the fracture height at failure when cracks occurred.

3. Results and discussion

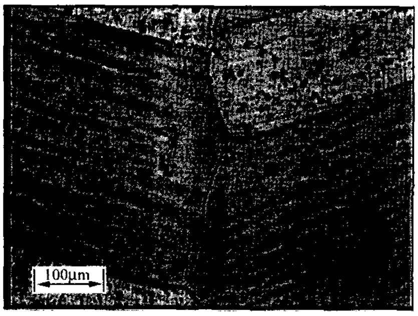
3.1 Grain size

Cr_{eq} and Ni_{eq} were calculated as 20.6 and 0.53 based on the equations provided by Schaeffler diagram. Thus, the microstructures of type 444 welds were 100% ferrites without any martensites forming in the weld metal shown in Fig. 1. Long columnar grains formed between the fusion line and the center of the weld. The weld centerline was continuous and very distinct. The narrow HAZ was observed as coarser grains occurred there as well.

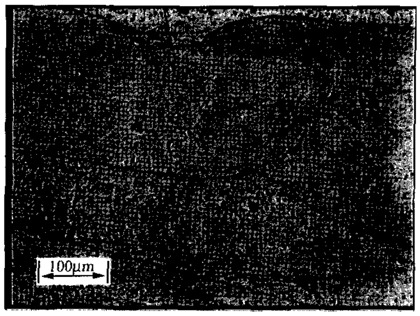
The detailed microstructures of weld metal made at frequencies of 0(DCSP), 30, 100, 150 and 200Hz with 120A, 50cpm were shown in Fig. 2. Clearly, pulse current has resulted in some grain refinement, although the degree of grain refinement was not considerable. In addition, the grain size in the weld metal made at a pulse



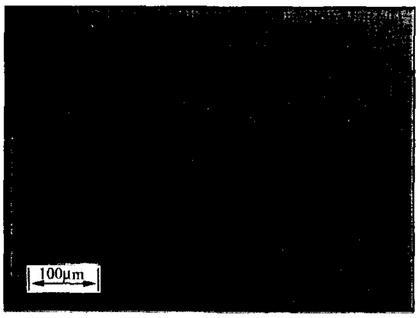
(a) 0Hz (DCSP)



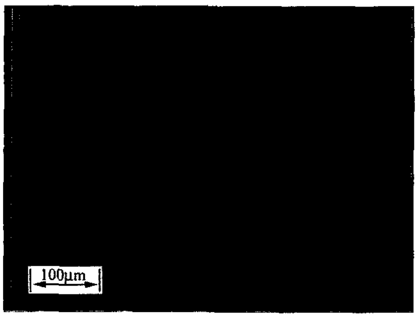
(b) 30Hz



(c) 100Hz



(d) 150Hz



(e) 200Hz

Fig. 2 Microstructures of the weld metal under the condition of 120A, 50cpm

frequency of 150Hz was observed to be the finest.

The result of quantitative grain size measurements in weld metal by WIG was shown in Fig. 3. This clearly demonstrated the superiority of pulsed current in refining the grain size in weld metal. Meanwhile, It was found that the grain size made at the frequency of 150 Hz was the finest in the condition of 120A, 50cpm and 90A, 30cpm. This is believed to be a consequence of the greater agitation in the weld pool caused by pulsed current. The pulsing of the welding current directly affects the temperature distribution, and the periodic variations of energy input into the weld pool cause thermal fluctuations[8].

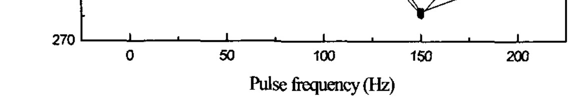


Fig. 3 Effects of pulse frequency on grain size by WIG

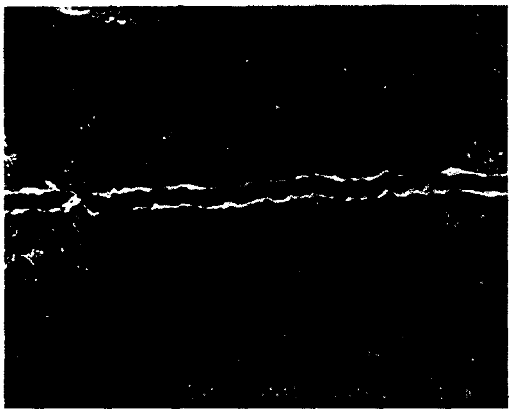
3.2 Varestraint test

Macro cracks in centre-line of weld metal and micro cracks in the top surfaces of Varestraint test welds were found, and the crack morphologies were shown in Fig. 4. Macro solidification cracks are cracks those can be detected on the surface with the naked eye. The micro cracks were observed with the aid of a microscope with a magnification of ×20, which are rather small and generally appeared perpendicular to the ripple line because augmented strain is applied. The center-line macro cracks were found only in the five out of the sixty specimens, thus autogeneous type 444 welds showed less susceptibility to macro cracks.

Effect of currents on the number of crack at the strain of 3.03% was given in Fig. 5, 175A of current was found to be less susceptible to the cracking at the two speeds. This result can be explained by the optimum weld pool geometry affected by the heat input, i.e. the optimum penetrations of weld bead obtained at the current of 175A can decrease the susceptibility of solidification crack.

SEM fractographs of solidification crack to the welds was given in Fig. 6, the fracture consist of two areas, one darker area representing the fresh opened fracture of

(a) Micro cracking



(b) Macro cracking

Fig. 4 Varestraint-induced solidification cracks morphologies in type 444 stainless steel

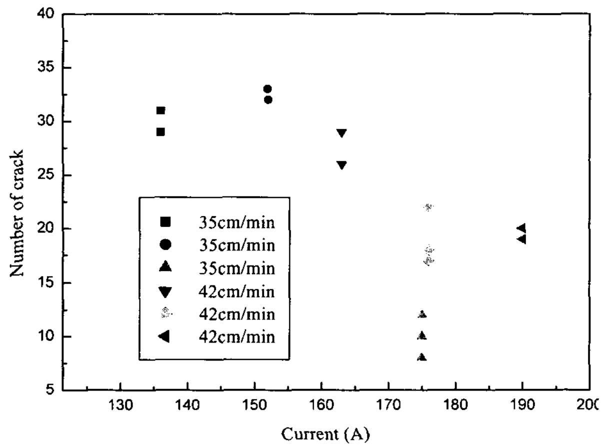


Fig. 5 Effect of the currents on the number of crack in Varestraint test for type 444

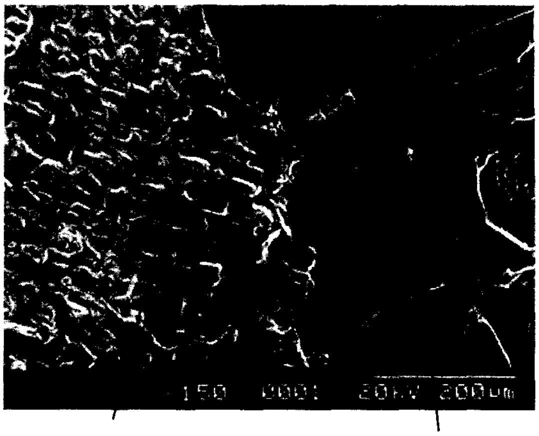


Fig. 6 Fractographs of Varestraint test for type 444

Fig. 7 SEM fractograph of oxidized solidification crack morphology

weld metal surface, and another brighter area representing the fracture surface due to the preexisting crack. The high magnification of oxidized solidification crack morphology was shown in Fig. 7. This kind of solidification crack morphology was observed because the solidification crack broken open has been oxidized when it was open to the surface. If not, different texture of the fracture surface may be apparent, with some rounding of the fracture surface detail at low magnification in comparison with the rest of the surface.

In order to identify the elemental segregation in the cracking area, SEM/EDS analysis was performed. The result showed that all the inclusions were observed enrichment of Mn, Si, O and S. The melting points of the sulphides (MnS, FeS, CrS) are much lower than that of Fe. If sufficiently high stresses are generated before final solidification, the boundaries enriched in Mn, Si, O and

S may separate to form solidification cracks in the fusion zone. However, the inclusions didn't show the enrichment of Nb.

3.3 Erichsen test

Fig. 8 presented the Erichsen results. It was observed that the Erichsen valunes of welds were found to be lower than that of base metal, that is, welds had lower ductility than that of the base metal. In addition, Erichsen values of pulsed current GTAW were higher than those of DCSP GTAW, that is, the pulsed current welding could obtain the better ductility than DCSP welding does, at least to some extent. In general, the ductility of ferritic stainless steel welds is reported to be low due to large grain size of the fusion zone.

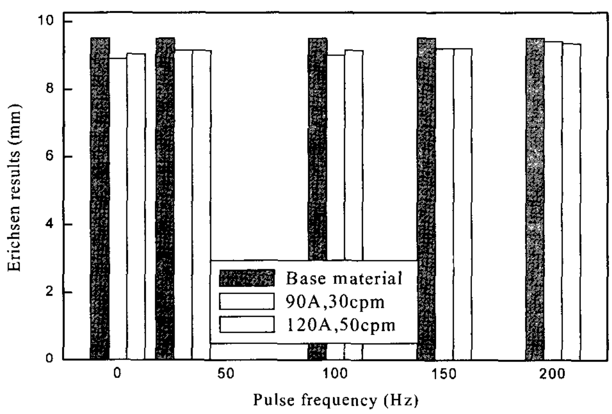


Fig. 8 Erichsen test results as a function of pulse frequency

4. Conclusion

The most important results of this study could be summarized as follows:

1. Pulsed current was beneficial to refine grain size in weld metal and the finest grain size was found at the frequency of 150Hz

2. Macro cracks in centre-line of weld metal and micro cracks in the top surfaces were found in the Varestraint test welds, however, autogenously type 444 GTA welds were less susceptible to macro cracks.

3. Type 444 GTA welds made at the current of 175A exhibited less solidification cracking susceptibility than those of the other currents. SEM/EDS analysis results showed all the inclusions enriched of Mn, Si, O and S.

4. The welds had lower ductility than the base metals, and pulsed current was effective to increase the ductility of the welds.

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