Effect of Welding Speed on the Microstructure and Mechanical Properties of Austenitic Stainless Steel Welds

C. Li and H. S. Jeong

Abstract

The effect of the welding speeds on the weld bead shape, microstructure, and mechanical properties in type 304 austenitic stainless steels was investigated by microscopic test, Erichsen test and tensile test. In this study welds were produced using autogeneous Direct Current Straight Polarity (DCSP) and pulsed current GTA welding. This study shows the ferrite content, ductility, tensile strength and elongation of high speed welds are decreased with increasing welding speed. The high speed welds exhibits satisfactory tensile strength, though the ductility is not good as that of the base metal.

Key Words : High speed welding, GTA welding, Delta-ferrite, Erichsen test, Tensile test.

1. Introduction

Austenitic stainless steels have been used widely, given their excellent high-temperature and corrosion resistance properties[1,2]. High speed welding is preferred in production line of austenitic stainless steels, and it is one way to effectively improve the quality and productivity of the welding process while reducing the overall cost. High speed welding has been achieved by robotic welding and laser welding. However, a few problems in laser welding of thin sheet steel limit the applications of laser welding in industries[3] and robotic welding also need to be considered the practical use, the optimal level of welding quality, reliability[4], and so on. In view of these, high speed welds were expected to be achieved by autogenous GTA welding to improve the productivity.

In the previous work, the welding speed has been improved from 1m/min-2m/min using Direct Current Strait Polarity (DCSP) GTA welding for type 304 plate of 0.5 mm thickness. In this study, welding speeds were controlled from 3m/min to 8m/min, and current was adjusted properly to get full penetration.

Many austenitic stainless steels exhibit a duplex austenitic-ferritic structure at room temperature after solidification. In welding austenitic stainless steel, it is important to take into consideration the ferrite content in the weld metal. The ferrite phase within the austenitic matrix is known to play a beneficial role in the prevention of hot cracking in as-welded structure[5]. With high travel speeds, rapid solidification of materials may produce microstructures during solidification that are markedly different from those observed during conventional solidification. It has been shown before that high cooling rates have altered the microstructures in stainless steel welds[6-8]. Thus, the objective of this paper was to investigate the effect of the welding speeds on the weld bead shape, microstructure, and mechanical properties in type 304 high speed welding.

2. Experimental procedure

Table 1 and Table 2 list the chemical compositions and mechanical properties of the base metal. Specimens are prepared with dimensions of 300×80×0.5 mm and are set firmly using welding jig to prevent distortion.

The autogeneous welds are made using DCSP and pulsed current welding along the center of the specimen under the following GTAW parameters given in Table 3. Welding speeds are increased from 3m/min to 8 m/min and current is also adjusted to give full penetration. The shielding gas used for the whole work is pure argon at a

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Table 1 Chemical composition of material used (wt.%)

Materials	C	Si	Mn	P	S	Ni	Cr
Type 304	0.07	0.46	0.78	0.032	0.006	8.10	18.32

Table 2 Mechanical properties of base metal

Y.S (N/mm^2)	T.S (N/mm^2)	El (%)	Hardness (Hv)
300	670	60	169

Table 3 Optimum welding conditions

Speed	DCSP	Pulsed Current	
(m/min)	Current (A)	Current (A)	Frequency (Hz)
3	110-130	115-125	60-500
4	140-150	140-150	40-500
5	160-180	160-175	100-500
6	210	200, 210	200-500
7	250,260	230,240	200-500
8	280,285	270	200-500

speed of 15L/min. Tip clearance is 2mm, and the base current is 60A when pulsed current welding is conducted.

Metallurgical sections are taken from each weld, transverse and longitudinal along the weld centerline. The mounted specimens are polished and etched electrolytically using 10% oxalic acid, and examined under the optical microscope and SEM. Magnetic gauge readings are taken to determine the Ferrite Number (FN) of the weld metal and base metal.

Erichsen test is carried out according to KS B 0812-74 for measuring the ductility of weld joint. According to KS B 0802-83, tensile test is conducted to check the tensile strength and elongation of welds. Five welding conditions are tested for a given travel speed, and three specimens are tested for each welding condition.

3. Results and discussion

3.1 Weld bead geometries of high speed welds

The relationship between welding speeds, weld pool geometry and fusion zone is shown in Fig. 1. Clearly, the width of welds and fusion sizes are decreased with increasing the welding speed from 3m/min to 8m/min. This result indicates that a lower welding speed results in a considerable increase in the fusion size and thus a decrease in Depth/Width ratio. Accordingly, the form of weld pool is clearly affected by the welding speed.

Table 1 and Table 2 list the chemical compositions and mechanical properties of the base metal. Specimens are prepared with dimensions of 300×80×0.5 mm^3 and are set firmly using welding jig to prevent distortion.

The autogeneous welds are made using DCSP and pulsed current welding along the center of the specimen under the following GTAW parameters given in Table 3. Welding speeds are increased from 3m/min to 8 m/min and current is also adjusted to give full penetration. The shielding gas used for the whole work is pure argon at a speed of 15L/min. Tip clearance is 2mm, and the base current is 60A when pulsed current welding is conducted.

Metallurgical sections are taken from each weld, transverse and longitudinal along the weld centerline.

The mounted specimens are polished and etched electrolytically using 10% oxalic acid, and examined under the optical microscope and SEM. Magnetic gauge

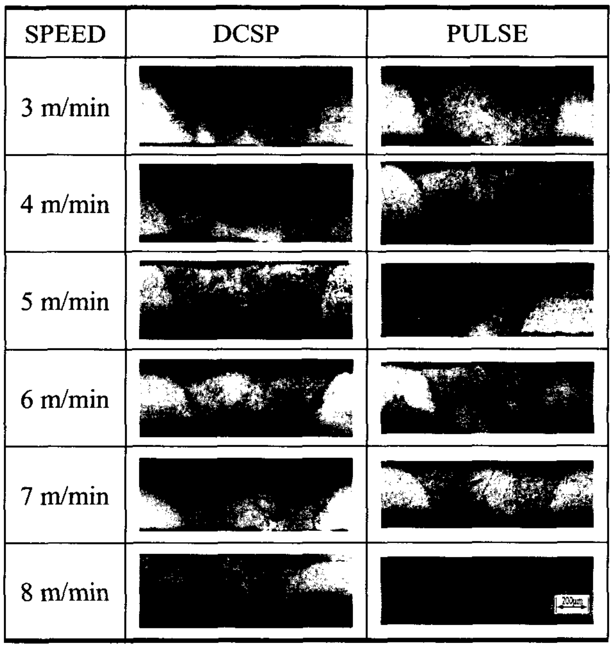

Fig. 1 Cross sections of high speed GTA Welding

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3.2 Microstructures of high speed weld metal

The microstructures of welds are austenite with a few percent of delta-ferrite. Both vermicular and lathy ferrites are observed in the high speed welds shown in Fig. 2. At the lower welding speed, vermicular ferrites are observed and lathy ferrites are found in the welds of higher welding speeds. As the speed increased, the vermicular structure is replaced by the lath-like ferrite. It also can be noticed that the higher the welding speed, the finer the dendritic structure.

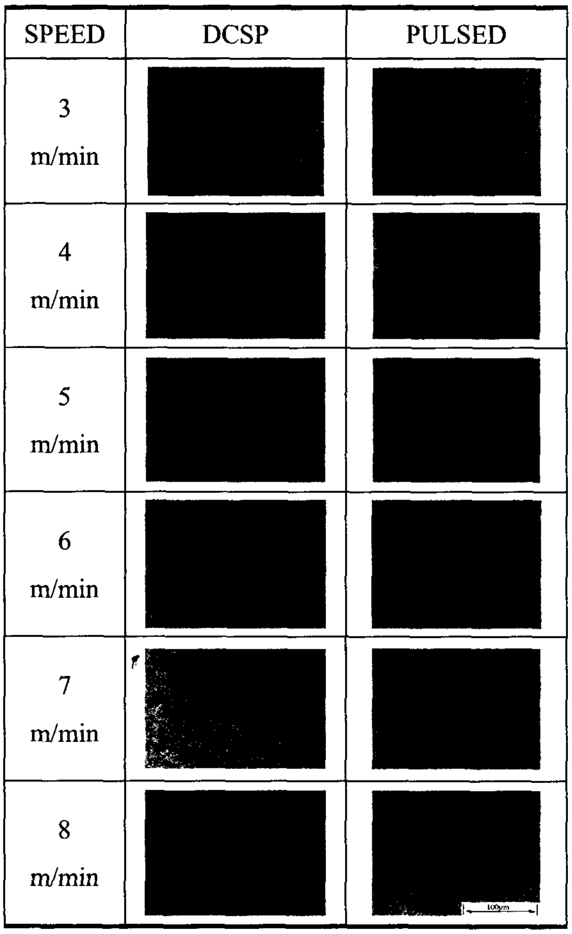


Fig. 2 Microstructures of high speed GTA welding weld metal

The amount of delta-ferrite can be estimated using Cr and Ni equivalents of chemical composition in the weld metal using the WRC-1992 diagram, and 6-8 vol% ferrite was derived to exist in the weld metal. However, the delta Ferrite Number (FN) measured in high speed weld metal by magnet-gage is less than 4FN given in Table 4. The FNs of the high speed welds vary from 3.2 to 2.3 with DCSP welding and from 3.1 to 1.6 with pulsed current welding within the weld speeds from 3m/min to 8m/min. This result suggested that the ferrite content of high speed weld metal decreased with the increase of the welding speeds. However, the cooling rate increases in the case of high speed welding, then the solid-state transformation of ferrite to austenite is retained, and then some residual ferrite remains in the as-welded structure. Therefore, it is usually found that the increase in the ferrite content with increasing cooling rate. The decrease in ferrite content with increasing cooling rates, observed at the higher welding speed can't be explained by the fact that the solid-state transformation is simply retarded at the higher cooling rates.

Table 4 Ferrite number in the high speed welds

Speed (m/min)		3	4	5	6	7	8
FN	DCSP	3.2	3.4	2.3	2.5	2.5	2.3
	Pulse	3.1	2.4	2.4	3.3	2.4	1.6

3.3 Erichsen test

It is observed from Fig. 3 that Erichsen values of high speed welds are decreased with increasing welding speed from 3m/min to 5m/min; The results from 5m/min to 8m/min reveal a saturation influence of speeds with DCSP welding from 5m/min to 7m/min. In comparison with the ductility of base metal, except at the speed of 3m/min, the others exhibit lower values than that of base material whether in DCSP or in pulsed welding, that is, high speed GTA welds had lower ductility than that of the base metals. This phenomenon can be explained by the ferrite content in the weld metal. The ferrite content is decreased in the high speed welds as was discussed above. Delta ferrite has a higher solubility of hot cracking-causing elements such as S, P, and Si[8)], therefore, the decrease of delta ferrite caused that these elements are released as a result of the dissolution of delta ferrite, and be redistributed by diffusion and grain boundary migration, degrading their ductility.

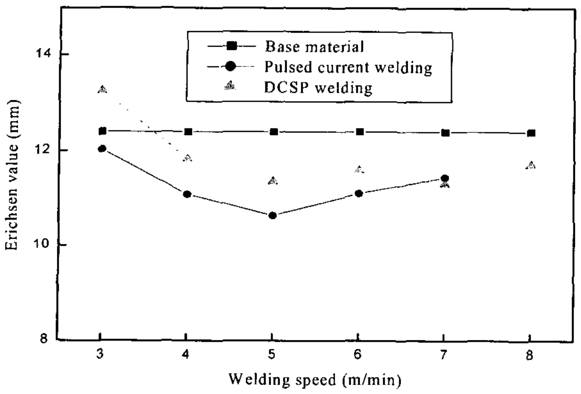


Fig. 3 Erichsen test results of high speed GTA welds

3.4 Tensile test

Fracture location of tensile test are shown in Fig. 4, and the fracture location is in the weld metal shown in specimen A or in the base metal shown in specimen B. The major criterion for the fracture position seems to be the elongation of high speed weld, e.g., if the elongations of welds are higher than that of base metal, the fracture occurred in the base metal; if not, fracture occurred in the welds.

Fig. 4 Fracture location of tensile test, A: in the weld metal; B: in the base metal

In Fig. 5 and Fig. 6 it may be noticed that increasing the welding speed results in decreasing the tensile strengths and elongations of high speed welds both in DCSP welding and in pulsed current welding, and the amount of drop in DCSP welds are greater than that of pulsed current welds. The occasional anomalous behaviors observed, for example, the result of 7 m/min, may be attributed to the data scattering.

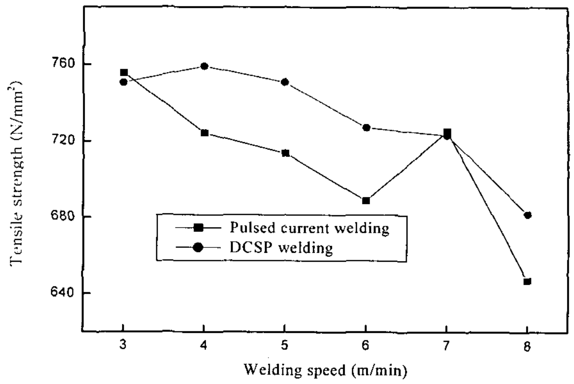


Fig. 5 Effect of welding sped on the tensile strength of the high speed GTA welds.

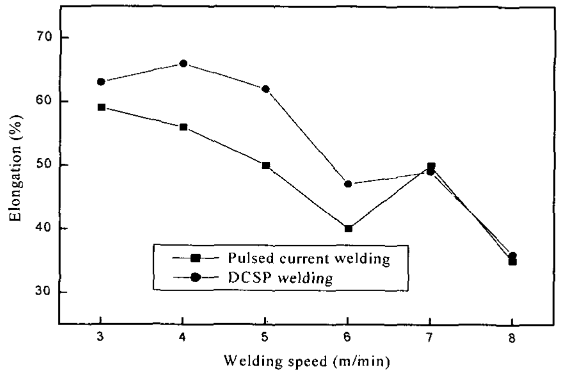


Fig. 6 Effect of welding speed on the elongation of the high speed GTA welds.

It is clear in Fig. 7 that almost all of the tensile strengths from 3m/min to 7m/min are quite high compared to that of the base metal. It is also observed in Fig. 8 that the elongation of DCSP welds from 3m/min to 5 m/min are higher than that of base metal. However, the others are low compared to that of base metal. In conclusion, the tensile strengths of welded joint are found to be satisfactory, and the elongations of weld are not as good as that of the base metal.

Fractographic observations made on the tensile test samples are shown in Fig. 9. The fracture surface of tensile strength of 613N/mm^2 in Fig. 9 (a) is mainly composed of large voids. These large voids may be formed by inclusions whose chemical compositions are analyzed elsewhere, and they were mainly MnS inclusions[9]. The initiation, growth and coalescence of these MnS inclusion-induced voids determine the elongation of type 304 welds. Fig. 9 (b) shows few voids, which exhibits higher tensile strengths.

4 Conclusion

Based on the experimental results described in the foregoing, the following conclusions could be drawn:

1. The form of weld pool is clearly affected by the welding speed. With the travel speed increased, the fusion zone sizes and the width of weld metal are minimized in high speed DCSP and pulsed current welding.
2. It can be found that the delta-ferrite content of high speed weld metal is less than 4FN and the ferrite content decreases with increasing welding speed. In addition, at the lower welding speed, vermicular ferrite morphologies are observed and lath ferrites are found in the higher welding speed welds. The higher the welding speed is, the finer the dendritic structure.
3. Erichsen values of high speed welds are decreased with increasing welding speed and high speed welds have lower ductility than that of the base metal.
4. The tensile strengths of high speed welds are decreased with increasing the welding speeds; the tensile strength results of high speed welds are found to be satisfactory, however, not all of the elongations of welds are good as the base material.

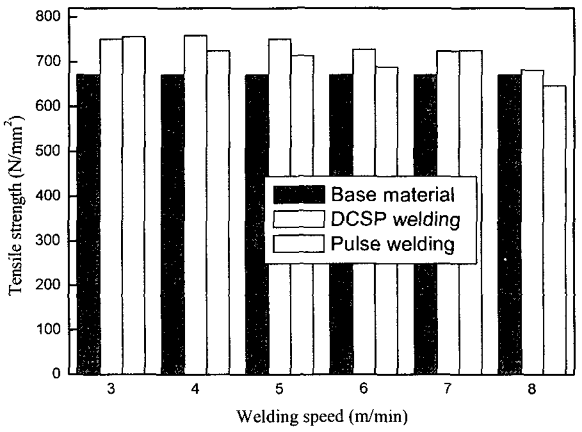


Fig. 7 Comparisons of tensile strengths with those of the base metal.

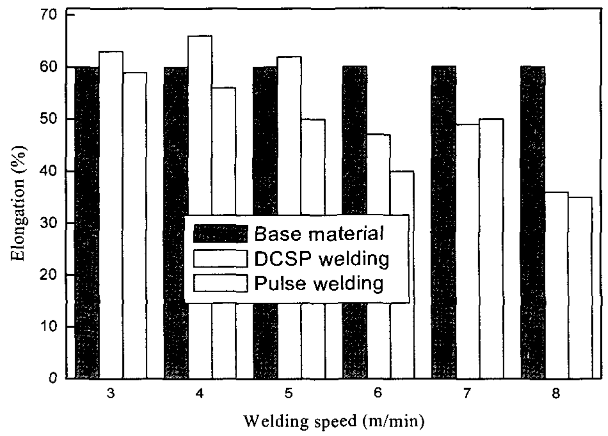
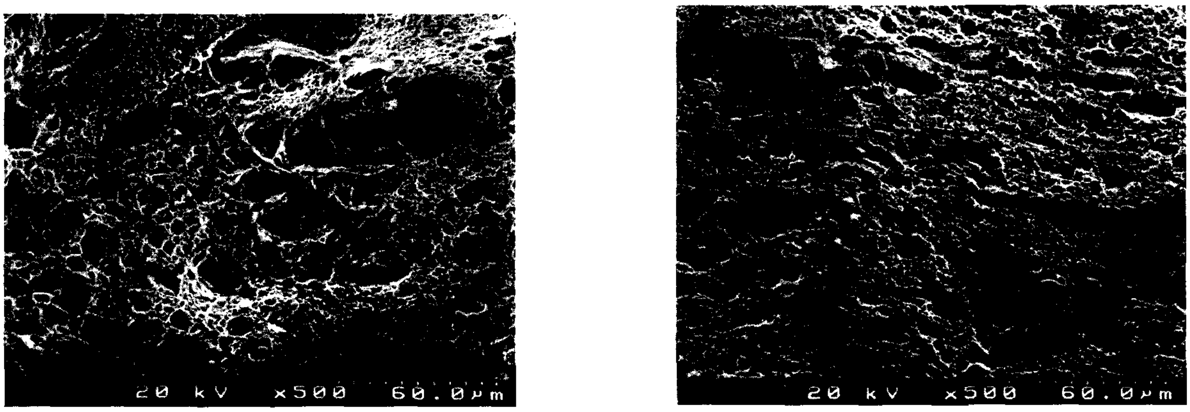


Fig. 8 Comparisons of elongations with those of the base metal.



(a) Tensile strength of 613N/mm^2

(b) Tensile strength of 770.7N/mm^2

Fig. 9 SEM photographs of fracture surfaces morphology of tensile test samples fractured at room temperature

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