A Effects of TIG Pulse Welding Parameters and Nitrogen Gas Mixed in Argon Shielding Gas on Weld Bead Formation and Microstructure of Weld Metals of AISI 304L Stainless Steels at the 10-h Welding Position

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Abstract

The present work investigates the effects of TIG pulse welding parameters and nitrogen gas mixed in Argon shielding gas on weld bead formation and microstructure of weld metals of AISI 304L stainless steels at the 10-h welding position. When the weld pool is shielded by Ar gas mixed with 1 vol.% of nitrogen, the pulse current that gives rise to the weld bead shape correspond to DIN 8563 quality class BS (I_p*) can be determined for the welding speed up to 4 mm/s. The higher I_p* is required at the higher welding speed to avoid the lack of fusion. The mixing of nitrogen gas to Argon shielding gas lowers I_p*, and reduces the ratio of delta ferrite in the austenite matrix.

Introduction

In order to reduce the distortion of the structure due to the welding process of thick stainless steels, the TIG pulse method has been applied for the root pass welding. It is then successively welded by the other techniques such as MIG, MAG or SAW. After the operation of the TIG pulse welding, the existing phases in weld metals are then modified. It was reported that if the delta ferrite is less than 3% in austenite matrix, the weld metal is prone to the solidification crack. This is due to the diminution of the ferrite phase, which possesses the higher solubility of sulfur than austenite.(1) However, if the delta ferrite is higher than 12 %, the delta ferrite tends to exist as the network surrounding the austenite.(2) This leads to the galvanic corrosion of the different phases as the corrosion network. It is then necessary to optimize the welding parameters in order to obtain the preferred ratio of delta ferrite in austenite matrix. The mixing of nitrogen gas, as the austenite stabilizer, to the conventional shielding gas has been applied to the TIG pulse welding of duplex stainless steels for this purpose.(3) Furthermore, as for the pipeline welding, the effect of welding position plays the critical role to the weld bead formation of the weld metal. This is especially when the welding position is subject to the influence of gravity. According to the previous work(4), the welding parameters, including the percentage of nitrogen gas mixed in Ar shielding gas, of the TIG pulse welding of AISI 304 stainless steels was studied at the flat, vertical and the overhead positions. The same TIG pulse parameters were also investigated in the case of TIG pulse welding of AISI 316L stainless steels.(5) The latter work studied the effect of TIG pulse frequency and percent on time of the pulse current on the depth-per-width ratio at the flat position. This is to find out the optimized values of those two parameters and set as the constants for the other welding positions. At the other welding positions, the pulse current that gives rise to the weld bead formation according to DIN 8263 quality class BS and were further found out. This pulse current was investigated as a function of the welding speed and the percent by volume of nitrogen gas mixed in Ar shielding gas. This approach of study is applied to the present work for the TIG pulse welding of AISI 304L stainless steels at the 10-h welding position.

Experiment

The Miller/Syncrowave 350 Ampere Constant Current AC/DC Arc is the welding equipment used in the study. The mode of pulse current DC straight polarity (DC electrode to be negative) is applied. The tungsten electrode, which contains 2% of thorium, has the diameter of 2.3 mm and the tip angle of 60°. The arc length is 2 mm. Figure 1 shows the welding table designed and built for the experiment, allowing the vertical rotation of the plate that holds specimens. Specimens are fixed by the screws on the plate, which is connected to the feed-screw conjoined to motor. The inverter is applied to control the translating speed of the plate that holds specimens up to 12.8 mm/sec.

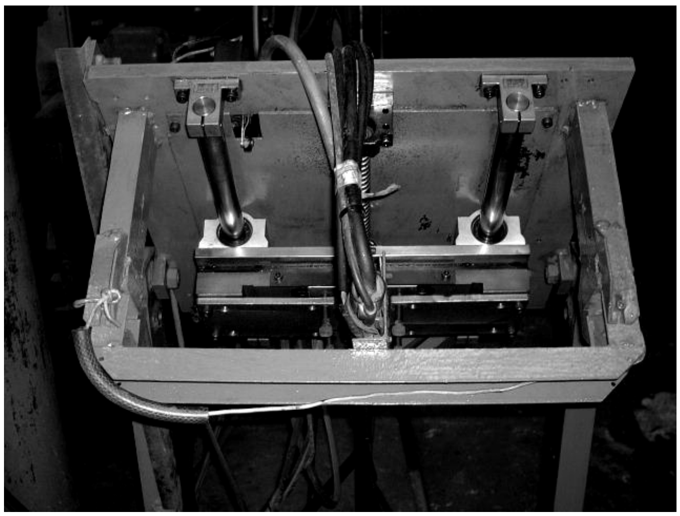


Figure 1. Welding table designed for the 10-h position welding experiment

The specimen is the AISI 304L stainless steel supplied as the sheet. The chemical composition is reported in table 1. It was cut to have the dimension of 100 x 50 x 2mm. The square butt joint was prepared for TIG pulse welding. After specimen was welded, the weld metal at the center of the line of weld bead was transversely cut. This is to measure the depth and width of the weld metal. The weld bead profile was further investigated according to DIN 8563 class BS.(6)

Table 1. Chemical composition (wt %) of Type 304L Stainless Steel

Chemical composition (% volume)										
C	Si	Mn	P	S	Cr	Ni	Mo	Nb	Fe	Others
0.0257	0.617	1.65	0.0484	0.01	17.52	11.71	0.0975	0.00949	67.74	0.5743

Results and discussion

The experiment at the 6-h welding position

Figure 2 depicts the depth(a) and width(b) of the weld metal as a function of pulse frequency at different percents on time. The experiment was conducted at the base current of 43 A, the pulse current of 105 A, and the welding speed of 3 mm/s. It appears that the application of 45% on time drastically increases the depth of weld metal. The increase in percent on time from 45% to 75% does not considerably increase the depth of weld metal comparing to the case that percent on time increases from 35% to 45%. It is also found, markedly for specimens welded by using 55% to 75% on time, that the pulse frequency does not affect the depth of weld metal. In figure 2(b), it appears that widths of specimens welded by applying 35% on time are wider than those of specimens welded by using 55% to 75% on time.

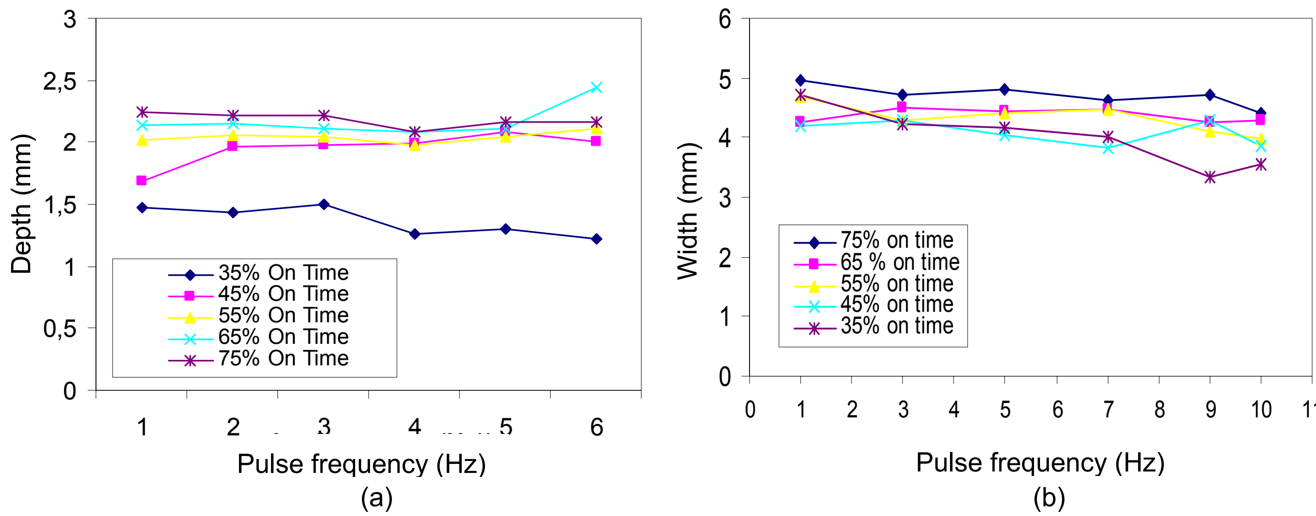


Figure 2. Depth(a) and width(b) of weld metal as a function of pulse frequency at different percents on time. (Welding condition: base current of 43 A, pulse current of 105 A and welding speed of 3 mm/s)

It seems that the width of weld metal is slightly lower when the pulse frequency is higher. The depth-per-width ratios are further plotted in figure 3.

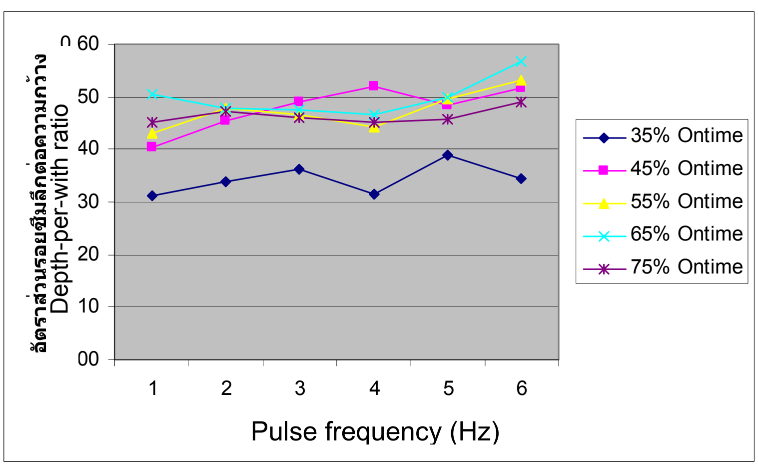


Figure 3. Depth-per-width ratio of weld metal as a function of pulse frequency at different percents on time. (Welding condition: base current of 43 A, pulse current of 105 A and welding speed of 3 mm/s)

It can be seen that depth-per-width ratio of specimens welded by applying the 35% on time is distinguishably lower than that of specimens welded by the applying of 45% to 75% on time. This ratio of specimens welded by using 45% to 75% on time is not considerably different. The application of 45% on time at the pulse frequency of 7 Hz promotes the relatively high ratio of depth-per-width of 0.52. This condition, 45% on time, still keeps the pulse characteristics of the TIG pulse welding process. They are then kept constant, with the base current of 43 A, for the further experiment at the 10-h welding position.

The experiment at the 10-h welding position

Specimens were welded by using the Ar shielding gas with the content of nitrogen gas of 0, 1 and 2 vol.%. At each shielding gas composition, the welding speed was varied from 3 up to 8 mm/s. The pulse current that gives rise to the weld bead shape correspond to DIN 8563 quality class BS (I_p*) was found out. In the case that pure Argon is applied as the shielding gas, I_p* can be determined at every welding speed in the studied range. When 1 vol.% nitrogen is mixed to Ar gas, I_p* can be determined for the welding speed up to 4 mm/s. At the higher welding speed, the low pulse current results in the lack of fusion. When the pulse current is increased to avoid this defect, the weld metal is instead suffered by the undercut. Nitrogen gas is further mixed to Ar gas with the content of 2 vol.%. At this condition, the slag inclusions are observed in weld metals at every values of the welding speed. The quality of the weld metal is summarized in table 2.

Table2. Quality of weld metals according to DIN 8563 quality class BS
(“ / ” means an acceptable weld metal, and “X” means an unacceptable weld metal)

Welding speed (mm/s)	Percent by volume of nitrogen gas mixed Ar shielding gas		
	0 vol.%	1 vol.%	2 vol.%
3	/	/	X (slag inclusion)
4	/	/	X (slag inclusion)
5	/	X (undercut)	X (slag inclusion)
6	/	X (undercut)	X (slag inclusion)
7	/	X (undercut)	X (slag inclusion)
8	/	X (undercut)	X (slag inclusion)

The I_p* that can be determined is plotted as a function of welding speed at 0 vol.% and 1 vol.% nitrogen in figure 4. It shows that when the welding speed increases, the higher pulse current is required. This is to avoid the lack of fusion. It also appears that the addition of nitrogen gas in Ar shielding gas lowers I_p*. This may be due to the higher heat conductivity of nitrogen gas compared to Ar gas.[6]

Figure 5(a) depicts the microstructure of the weld metal shielded only by the Ar gas. The microstructure of the weld metal shielded by Ar gas mixed with 1 vol.% nitrogen gas is shown in figure 5(b). Figure 6 exhibits the ratio of ferrite in austenite matrix of specimen welded by using the pure Ar shielding gas and the Ar gas mixed with nitrogen with the content of 1 vol.%. It shows that the mixing of nitrogen gas reduces the ratio of ferrite in austenite matrix. This implies the possibility to mix nitrogen gas in Ar shielding gas in order to modify the ratio of delta ferrite in austenite matrix.

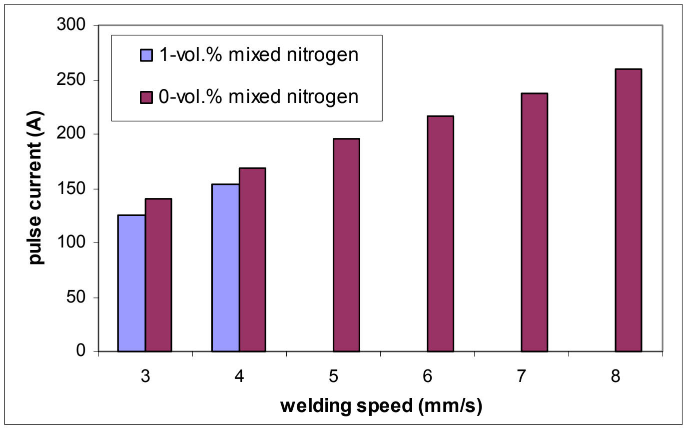
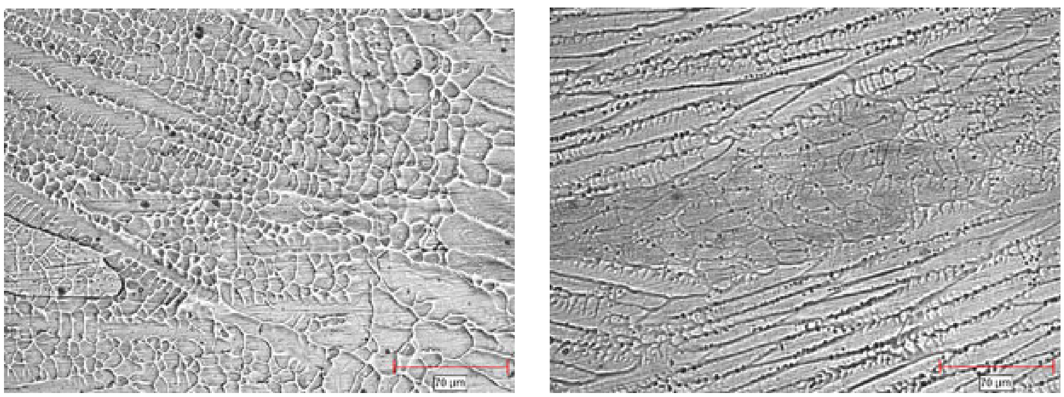


Figure 4. The pulse current that gives rise to the weld bead shape correspond to DIN 8563 quality class BS (I_p*). (Welding condition: pulse frequency of 7 Hz, 45% on time and base current of 43 A)



(a) (b)

Figure 5. Microstructure of weld metals of specimens welded by using (a) Ar shielding gas, (b) Ar shielding gas mixed with 1 vol.% of nitrogen gas. (Welding condition: pulse frequency of 7 Hz, 45% on time, base current of 43 A, pulse current of 155A and the welding speed of 4 mm/s)

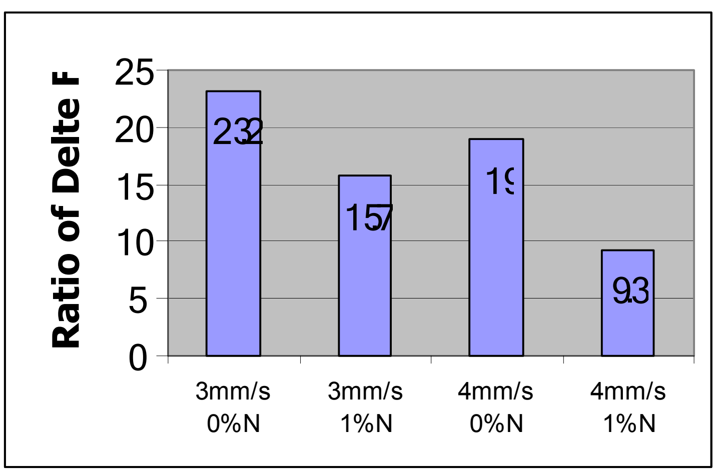


Figure 6. The ratio of delta ferrite in austenite matrix of specimens welded by using pure Ar gas and Ar gas mixed with 1 vol.% of nitrogen at the welding speed of 3 and 4 mm/s. (Welding condition: pulse frequency of 7 Hz, 45% on time, base current of 43 A.)

Conclusion

The preliminary experiment at the 6-h welding position was conducted to find out the pulse frequency and percent on time that causes the appreciated depth-per-width ratio. They were then set as the constants for the further experiment at the 10-h welding position. At the 10-h welding position, nitrogen gas can be mixed to Ar with the content of 1 vol.% without the slag inclusion problem in meld metal. At this shielding gas composition, the pulse current that gives rise to the weld bead shape correspond to DIN 8563 quality class BS (I_p*) can be determined for the welding speed up to 4 mm/s. The higher I_p* is required when the welding speed is higher in order to avoid the lack of fusion. It was found that the mixing of nitrogen gas to Ar shielding gas lowers I_p*, and reduces the ratio of ferrite in austenite matrix. The latter result implies the possibility to mix nitrogen gas in Ar shielding gas in order to modify the ratio of delta ferrite in austenite matrix.

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References

[1] J.F. Lancaster, *Welding Metallurgy*, 5th Edition, Chapman&Hall, Cambridge, U.K., 1994.
[2] J. Ruge, *Welding Handbook,* Springer Verlag, Berlin, Germany, 1991.
[3] R.K. Huismann and H. Hoffmeister, Investigation of the Effects of TIG Pulse Parameters and Shielding Gas Compositions on Weld Bead Formation and Microstructure of Duplex Stainless Steel Orbital TIG Root Welds, *LWS Report*, University of Federal Armed Force, Hamburg, Germany, 1992.
[4] G. Lothongkum, P. Chaumbai and P. Bhandhubanyong, TIG pulse welding of 304L austenitic stainless steel in flat, vertical and overhead positions, *Journal of Materials Processing Technology*, Volumes 89-90, 19 May 1999, pp. 410-414
[5] G. Lothongkum, E. Viyanit and P. Bhandhubanyong, Study on the effects of pulsed TIG welding parameters on delta-ferrite content, shape factor and bead quality in orbital welding of AISI 316L stainless steel plate, *Journal of Materials Processing Technology*, Volume 110, Issue 2, 19 March 2001, pp. 233-238.
[6] Deutches Institut für Normung e.V., *DIN Handbook 8 : Welding 1 Standard dealing with filler metal, manufacture, quality and testing*, 3th edition, Beuth Verlag, Germany, 1991.
[7] F.C. Hull, Effect of Delta ferrite on the Hot Cracking of Stainless Steel, September 1967, pp. 399-408.
[8] J.A. Brooks, A. W. Thompson And J.C. Williams A Fundamentals Study of the Beneficial Effects of Delta Ferrite in Reducing Weld Cracking, Welding, *Research Supplement*, March 1984, pp. 71 to 83.
[9] R.K. Okagawa, R.D. Dixon AND D.L. Olson, The Influence of Nitrogen from Welding on Stainless Steel Weld Metal Micro Structures, *Welding Research Supplement*, August 1983, pp. 204 to 208.
[10] T. Ogawa, K. Suzuki AND T. Zaizen, The weld ability of Nitrogen-Containing Austenitic Stainless Steel: Part II-Porosity, Cracking and Creep Properties, *WELDING RESFARCH SUPPLEMENT*, July 1984, pp. 213 to 223.
[11] T. Ogwa AND T. Koseki, Weld Ability of Newly Developed Austenitic Alloys for Cryogenic Service: Part II High-Nitrogen Stainless Steel Weld Metal, *Welding Research Supplement*, January 1988, pp. 8-17.
[12] W.T. Delong, G A Ostrom AND E.R. Szumachowski, Measurement and Calculation of Ferrite in Stainless Steel Weld Metal, November 1956, pp521-528.