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Optimization of Process Parameters of Pulsed Current TIG Welding for Ferrite Content of DSS Joints

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Abstract: In this investigation an attempt has been made to optimize the parameters of pulsed current TIG (PC TIG) to obtain desirable ferrite content in terms of Ferrite number (FN) for 2205 Duplex stainless steel joints fabricated using 2209 filler. Taguchi orthogonal array (OA) experimental design (DOE) along with statistical tools such as Analysis of Variance (ANOVA) and Pooled ANOVA techniques were used for the above purpose by using the four process parameters namely pulsed current, background current, pulse on time, pulsed frequency in three different levels. The pulsed current is the most significant factor on ferrite number with contribution followed by pulsed frequency. The background current and pulse on time are insignificant. Among the four parameters pulsed current is the most significant factor to control Ferrite content in DSS joints considered in this investigation. The optimized process parameters are : Pulsed current (160 A background current (90 A), pulsed frequency (3 HZ), pulse on time (40 %). Under these conditions, FN is predicted to be 76.84 and ferrite content is 54.32 % which is well within the desired value of 30 % to 55%
Keywords: Pulsed current TIG welding , Ferrite number, Duplex stainless steel.

I. INTRODUCTION

Duplex stainless steel (DSS) has dual phase microstructures consisting of approximately equal proportions of body-centred cubic ferrite and face-centred cubic austenite. In view of the above DSS is a common structural material in the oil and gas industries, and has special applications in chemical, wastewater, and marine engineering fields as well. [1–2]. Welding process, filler metal additions, shielding gas and heat input are important factors control the austenite-ferrite phase ratio (1:1) in the weld metal region. The mode of metal transfer is one of the significant factor for establishing austenite-ferrite phase ratio in DSS joints. Pulsed current gas tungsten arc welding (PCTIG) is a joining technology, developed in 1950s which is a variant of the constant current gas tungsten arc welding (CCGTAW) process which involves cycling of the welding current from a high level to a low level at a selected regular frequency. The various parameters are illustrated in Fig 1. The PC-TIG process has a numerous advantages over the constant current GTAW process includes (i) refined grain size, (ii) low distortion, (ii) enhanced arc stability, (iv) reduced porosity, (v) increased weld depth to width ratio, (vi) reduction in the heat-affected zone (HAZ), and (vii) better control of heat input [1]. In general, the Pulsed current TIG welding process is suitable for joining thin and medium thickness materials, e.g., stainless steel sheets, and for applications where metallurgical control of the weld metal is critical [3-4]. Duplex stainless

The purpose of the present investigation is to optimize the PC-TIG welding process parameters to obtain the desirable ferrite content of duplex stainless steel welds using Taguchi orthogonal array (OA) experimental design (DOE) and other statistical tools such as Analysis of Variance (ANOVA) and Pooled ANOVA techniques [5].

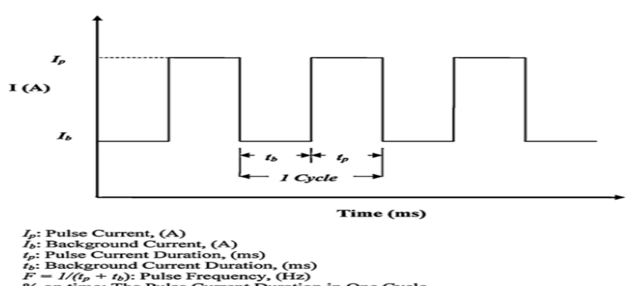

Fig 1. Pulesed current wave form

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II. EXPERIMENTAL PLAN

The following order of plan to optimize the process parameters for PC-TIG welding for 2205 DSS joints are detailed below:

A. Finding the Important Process Control Parameters

In this study , the duplex stainless steel 2205 selected as a base metal and ER2209 filler was used. The chemical composition of base metal and filler materials is presented in table 1. The microstructural feature of the base metal exhibits a duplex structure with embedded grains of austenite (A) and ferrite(F) as shown in Fig 1. . The microstructure of DSS roughly 50% austenite and 50% ferrite, microstructure of DSS shown in fig 2[6].

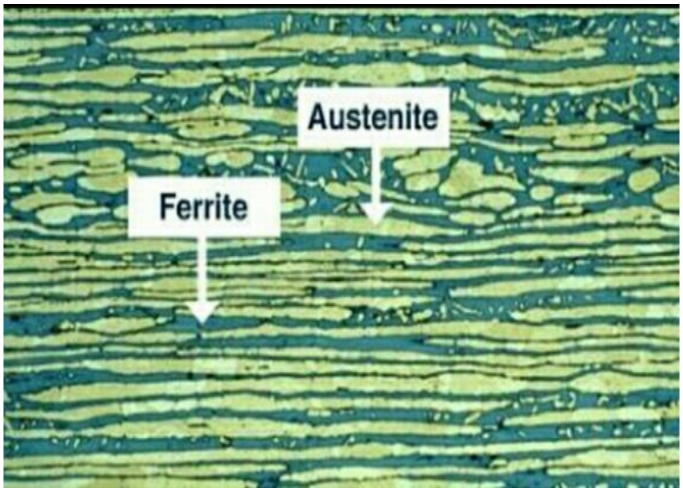

Fig 2. Microstructure of duplex stainless steel

The process parameters of pulsed current TIG welding process that control ferrite number of DSS joints are identified as : (i) pulsed current , (ii) background current, (iii) pulsed frequency and (iv) pulse on time[1] . The range of the parameters were decided based on the several experimental trails and are illustrated in Table 2.

B. Selecting The Levels of The Process Control Parameters

The level of the experiment is given in table 2 based on several experimental trails.

C. Selection of the Experimental Design Matrix

Taguchi method is an efficient problem solving tool, used for improveing the performance of the product, process, design and system with a significant slash in experimental time and cost . Taguchi method of L9 orthogonal array (OA) (Table 3), was chosen as it was most suitable for the investigating four parameters each with three levels [7]. The order of the experiments was obtained by inserting parameters into the columns of the OA, L_9 (3^4), chosen as the experimental plan given in Table 3.

Taguchi method recommends the signal-to-noise (S/N) ratio, which is a performance characteristic, instead of the average value. Optimum conditions were determined using the S/N ratio from experimental results . There are three S/N ratios of common interest for the optimization of static problem, i.e., the higher the better (HB), the lower the better (LB), and the nominal the better (NB). The larger S/N ratio represents to better performance characteristic. Further more,a statistical analysis of variance (ANOVA) can be performed to see which process parameters is statistically significant for each quality characteristics.

D. Conducting the Experiments as Per The Design Matrix And Recording Of Responses

The plates of 4 mm thick base metal were sliced into the required dimensions (150mm x 100mm) by abrasive cutters and Single 'V' Butt joints were fabricated by pulsed current TIG welding using ER 2209 filler material.

The direction of welding was normal to the rolling direction. All necessary care was taken to avoid joint distortion and the joints were made after clamping the plates in a welding fixture.

The welding was carried out using a pulsed current TIG welding machine . High purity argon (99.99%) used as a shielding gas for pulsed current TIG welding with a flow rate of 18 liters per minute. The welding was carried out in sequential order with the

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parameters as shown in Table 3. The ferrite content interms of Ferrite number (FN) was measured in the weld zone by using ferrite scope at five different locations and the average values are used for further analysis and they are listed in Table 4.

Table 1. Chemical composition of base metal and filler material

Material	C	Mn	P	S	Si	Cr	Ni	Ti	Mo	Cu	Fe
Duplex stainless steel 2205	0.014	1.36	0.018	0.001	0.4	22.3	5.68	0.006	3.1	0.14	Bal
Filler material ER2209	0.028	0.80	0.018	0.016	0.8	22.0	9.00	-	3.00	-	Bal

Table 2. Process parameters and their levels

parameters	Units	Notation	Levels					
			Original			Coded		
			Low	Medium	High	Low	Medium	High
Pulse current	Ampere (A)	A	120	140	160	1	2	3
Background current	Ampere (A)	B	80	80	90	1	2	3
Pulse frequency	(HZ)	C	5	5	7	1	2	3
Pulse on time	(%)	D	40	50	60	1	2	3

Table 3. Experimental layout using L9 orthogonal array with coded and original level values

Trial no	Parameters/factors							
	Pulse current[A] Ampere		Background current [B] ampere		Pulse frequency [C] HZ		Pulse on time [D] Sec	
	Original value	Coded value	Original value	Coded value	Original value	Coded value	Original value	Coded value
1	120	1	70	1	3	1	40	1
2	120	1	80	2	5	2	50	2
3	120	1	90	3	7	3	60	3
4	140	2	70	1	5	2	60	3
5	140	2	80	2	7	3	40	1
6	140	2	90	3	3	1	50	2
7	160	3	70	1	7	3	50	2
8	160	3	80	2	3	1	60	3
9	160	3	90	3	5	2	40	1

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Table 4. Experimental results and Corresponding S/N ratios and Ferrite number

Trial no	Process parameters				responses	S/N ratio (dB)	Heat input (kj/mm)
	Pulse current (A)	Background current (A)	Pulse frequency (HZ)	Pulse on time (Sec)	Ferrite number (FN)		
1	120	70	3	40	59.22	35.44	0.431
2	120	80	5	50	60.65	35.65	0.454
3	120	90	7	60	63.5	36.05	0.477
4	140	70	5	60	66.37	36.43	0.477
5	140	80	7	40	67.85	36.63	0.5
6	140	90	3	50	73.51	37.32	0.522
7	160	70	7	50	70.65	36.98	0.522
8	160	80	3	60	77.8	37.81	0.545
9	160	90	5	40	82.08	38.28	0.568
Average S/N ratio						36.73	

Table 5. S/N response table for ferrite number

Parameters	Character	Level 1	Level 2	Level 3	Delta =maximum-minimum	Rank
Pulse current	A	35.71	36.79	37.69	1.98	1
Background current	B	36.28	36.69	37.01	0.73	3
Pulse frequency	C	36.85	36.78	36.55	0.84	2
Pulse on time	D	36.78	36.65	36.76	0.13	4

Table 6. Results of the ANOVA for ferrite number

Character	Parameters	Degree of freedom	Sum of squares (ss)	variance	Corrected sum of squares	contribution (%)	Rank	Significant
A	Pulse current	2	589.6	294.8	589.6	7.9	1	Yes
B	Background current	2	130.35	65.17	130.35	1.76	3	No
C	Pulse frequency	2	147.9	73.95	147.9	2.006	2	Yes
D	Pulse on time	2	29.4	14.7	29.4	0.398	4	N0
Error		0	0	0	0			
Total		8	897.2					

Table 7. Pooled ANOVA for ferrite number

Character	Parameters	Degree of freedom	Sum of squares (ss)	variance	Corrected sum of squares	Contribution (%)
A	Pulse current	2	589.6	294.8	509.74	6.914
B	Background current	(2)	130.35	pooled	-	-
C	Pulse frequency	2	147.9	73.95	147.9	0.922
D	Pulse on time	(2)	29.4	pooled	29.4	-
Error		4	159.72	39.93		92.164
Total		8	897.2			100

Table 8.Evaluation of the predicted ferrite number with the experimental results of the confirmation experiment using optimal condition

Parameter	A	B	C	D	S/N ratio		Performance values of ferrite number (FN)	
	Pulse current (A)	Background current (A)	Pulse frequency (HZ)	Pulse on time (sec)	prediction	experim ent	Prediction	Experim ent
Optimum coded value	3	3	1	1	38.24	37.71	82.54	76.84
Optimum Original value	160	90	3	40				

E. Calculate The Signal to Noise (S/N) Ratios

In this study, an L9 OA with 4 columns and 9 rows was used. This array can handle three-level process parameters. Nine experiments were necessary to study the welding parameters using the L9 OA. In order to evaluate the influence of each selected factor on the responses, the S/N ratios for each control factor has been calculated using the following equation as detailed in the literature [8]. Table 4 shows the experimental results for Ferrite Number (FN) and the corresponding S/N ratios. The mean S/N ratio for each level of the parameters is summarized and the S/N response table for ferrite number is shown in Table 5. The rank 1 in the Table 5 indicated that pulsed current has significant effect on the ferrite content followed by background current, pulsed frequency and pulse on time. The higher the better criteria was used for analysis for evaluating the S/N ratio by using the equations detailed in the literature [5,8].

F. Analysis of variance (ANOVA)

The ANOVA is a common statistical technique to determine the percent contribution of each factor for results of the experiment [9]. In ANOVA, sum of squares (SS), corrected sum of squares (SS'), degree of freedom (D), variance (V), and percentage of the contribution of each factor (P) were calculated by using the equations as detailed in the literature [10]. The pulsed current is the most significant factor on ferrite number with 7.9 % contribution followed by pulsed frequency with 2.006% contribution. The background current and pulse on time are insignificant with contribution of 1.76% and 0.398%, respectively.

G. Pooled ANOVA

The process of disregarding an individual factor contribution and then adjusting the contribution of the other factor is known as pooling. The results of ANOVA after pooling for ferrite number were calculated using the equations as detailed in the literatures

[11] are presented in Table 7. Pooled ANOVA values reveal that the pulsed current (6.914%) is a significant factor for the ferrite number in the pulsed current TIG welding process.

H. Confirmatory test to Check the Optimized Process Parameters

The optimized process parameters were checked and verified for quality characteristic The predicted S/N ratio using the optimal level of the design parameters is calculated by equations as described in literature [12-13] and are illustrated in Table 8 .There is good agreement between the predicted and the experimental Ferrite Number is being observed.

III. CONCLUSION

In this study, the PC-TIG welding process parameters were optimized for ASTM/UNS S32205 DSS joints to obtain the desirable ferrite percentage, and the results were analysed in detail. Analysis of variance (ANOVA) and pooled (ANOVA) techniques were used to examine the most significant factor. We can find the following conclusions

A. The pulsed current is the predominant factor that affects the ferrite number of DSS welds fabricated using pulsed current TIG welding process.
B. The optimum welding parameters are found to be for pulsed current of 160 A, background current of 90A, pulsed frequency of 3 HZ and pulse on time of 40%.
C. Average ferrite number (FN) in the weld zone for the joints fabricated using the optimized process parameters is 76.84, and the ferrite content is approximately 54.32% which is well within the acceptable range.

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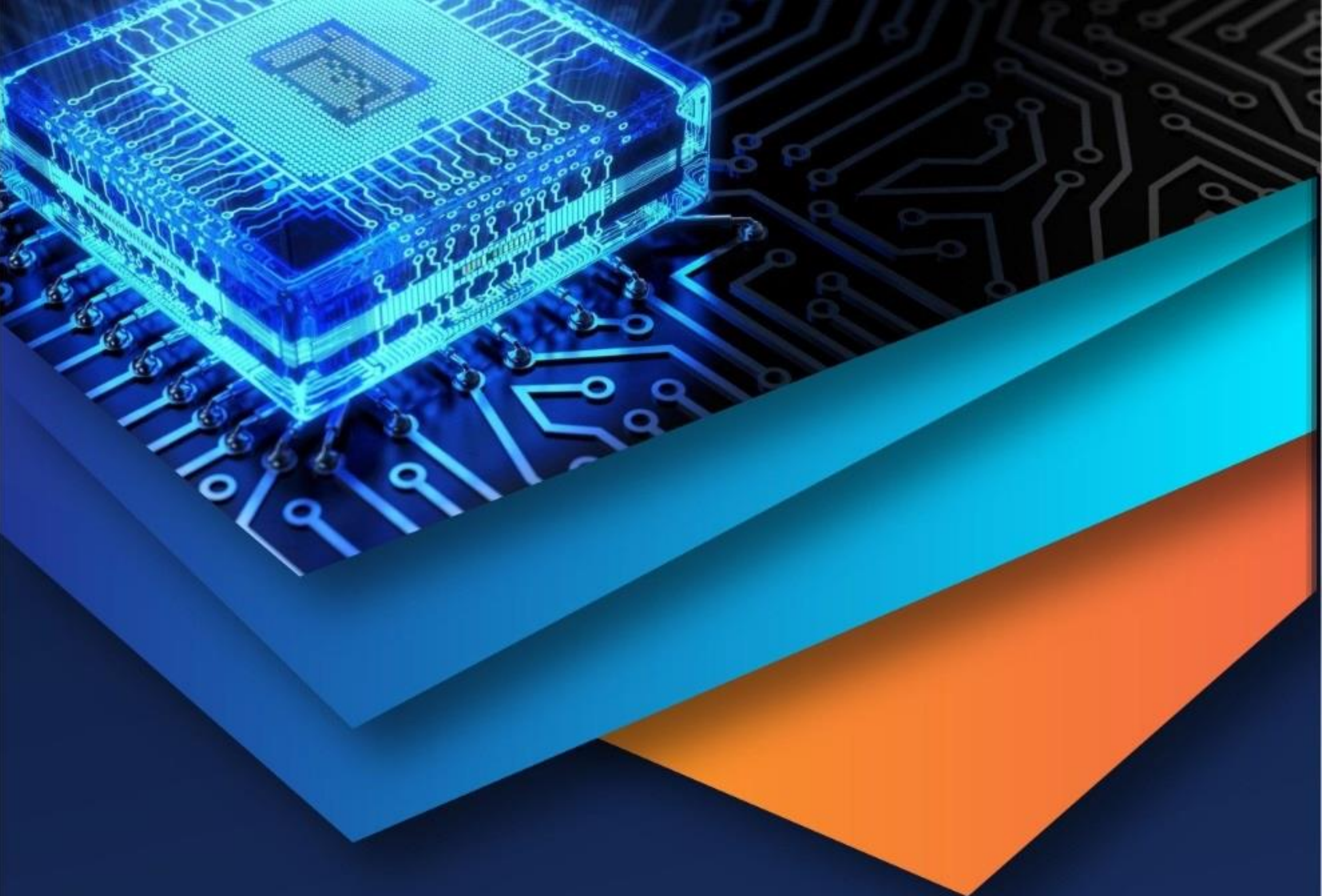

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