PARAMETRIC OPTIMIZATION OF COLD METAL TRANSFER WELDING PROCESS ON AISI 202 AUSTENITIC STAINLESS STEEL

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ABSTRACT

For better efficiency, manufacturers these days are more interested in using very light weight materials that not only reduces the overall weight of the structure but also enables the use of latest technology. Due to their immense strength, ease in fabrication, Austenitic Stainless Steel grades find their application in wide range of manufacturing industries such as automotive, medical, construction, aerospace. Various problems such as burn through, distortions, spatter and other defects were reported when thin austenitic stainless sheets were welded using conventional arc welding process because of their high heat input. Cold Metal transfer welding is a modern era welding technology for joining of thin sheets as optimum penetration at low heat input and spatter free weld can be obtained. In this research work SS202 samples of thickness 1.58mm have been welded using SS308 filler wire by CMT welding process. Three different levels of Current (80A, 100A, 120A), Welding speed (3mm / sec, 4mm / sec, 5mm / sec), and Pulse dynamic correction Factor (-10, 0, +10) were set as input process parameter. The experiments have been carried out at most optimum parametric combination obtained from Taguchi L9 design of experiment array. The superiority of weld was estimated in the form of three mechanical properties Yield Strength (YS), Ultimate Tensile Strength (UTS), and Percentage Elongation wherein highest value obtained for the three were 379 MPa, 871 MPa, and 65.9 % respectively. The experimental data obtained have been optimized by Taguchi's S / N ratio larger the better criteria.

KEYWORDS: CMT, Yield Strength, Ultimate Tensile Strength, Percentage Elongation, Pulse dynamic Correction Factor, Taguchi

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1. INTRODUCTION

Austenitic stainless sheets of grade 200 series and 300 series are used extensively in manufacturing industries because of their excessive value of strength, resistance to temperature, ease of fabrication. [1]. HSLA steels find their extensive utilization in ship building, and has several other industrial applications because of its favorable mechanical properties and excellent weldability. [2-3]. Austenitic steel grade such as SS202 which is having high chromium and manganese content is less expensive material as compared to other grades having comparable strength and shows excellent toughness and stability at room temperature. Yield Strength of SS202 increases because of addition of manganese [4]. Higher strength to weight ratio is reported for SS202 amongst other austenitic stainless steel grades [5]. Higher limiting draw ratio is reported for SS202 as compared to SS304 austenitic stainless steel grades [6]. These properties make SS202 suitable material to be used as plates or sheets in the manufacturing of cooking utensils, motor shafts of boats, railway components, medical devices, restaurant equipment, automotive trim, sink and many more items [7-8]. Presence of high nickel content in SS304 makes it corrosion resistance. Addition of molybdenum and its low carbon content composition makes AISI 316L most suitable material to be used in manufacturing of furnace parts, exhaust

manifold, jet engine and heat exchanger as it is having corrosion resistant property [9]. Traditionally all these materials were welded by using arc welding method like MIG / MAG welding, TIG welding. Welding of thin sheets of these materials is very difficult at constant high heat energy that is given in these conventional process. During the welding process temperature variation in the parent metals and the welds shows effect on heat affected zone, dimensional accuracy, residual stresses and microstructure characteristics of the weld [10].

Koli et al. [11] reported that for same current CMT showed low amount of bead penetration when evaluated against MIG Pulse and MIG manual, hence thin sheets can be welded by using CMT. Cold Metal Transfer Welding is a latest technology which is modification to MIG welding. In this superior welding technology, the filler wire is drawn backward and forward which is an alternative to continuous wire feed with the aid of a creative wire feed system which is coupled with control system [12]. The detachment of droplet during short-circuit is assisted by this wire retraction motion hence, the droplet is fetched into the weld pool without any help of the electromagnetic force [13]. Using CMT welding process accurate material deposition rates are obtained and current parameters are controlled very precisely, this helps in giving low thermal energy which is ample and adequate to liquefy both filler wire and base material hence, less distorted spatter free weld bead is obtained [14]. The above quoted advantages of CMT welding technology makes it suitable process for joining various similar and dissimilar metal [15]. Frostevar et al. [16] reported that CMT arc mode showed better weld bead stability, less under cut, less heat affected zone and required less power as compared to pulsed and standard arc mode. Stanciu et al. [17] reported that by reducing wire feed rate reinforcement in CMT welding can be reduced whereas increasing the welding speed results in improper penetration. Defect free and porosity less weld overlay of Inconel 617M over SS316 sheets can be obtained by Cold Metal Transfer Welding Process. [18]. An optimum penetration of the weld bead with high dilution and a huge depletion in residual stresses value was discovered by Koli et al. [19] using CMT joining technology. Lei et al. [20] investigated the properties of CMT welded AA6061 aluminum alloy. In test results it was reported that the weld bead obtained by CMT arc mode was reported to have least welding defects with negligible distortions. Further the test result data discloses that the best mechanical properties were obtained using CMT arc mode in comparison to standard and pulsed mode. Luchtenberg et al. [21] investigated the microstructural properties of weld bead formed while welding S32205 Duplex stainless steel of 12mm thickness using ER2209 filler wire of diameter 1.2 mm by cold metal transfer welding process. Different sets of experiments were conducted at 3 different levels of welding speed i.e. at 15cm / min, 23cm / min and 30cm / min wherein the current value was kept constant at 215A. The experimental result concluded that change in heat input changes ferrite / austenite balance. As the energy increases inter granular austenite formation also increases. But the formation of ferrite decreases. Bunaziv et al. [22] investigated the weld bead properties of high strength low alloy steel welded by hybrid laser arc welding in cold metal transfer welding mode by preplacing the wire in the weld groove prior to welding. The test result concluded that preplacement of the wire in the weld groove significantly improved the stability and homogeneity of the weld. Reisgen et al. [23] investigated mechanical and microstructure properties of the weld bead of austenitic stainless steel AISI 304 samples of thickness 3 mm welded by cold metal transfer welding process using ER 308LSi filler wire of diameter 0.8mm and 1.2mm. For shielding gas, mixture of argon and carbon dioxide was used with Ar as 97.5% and CO₂ as 2.5%. The test result concluded that all the sample undergone ductile fracture. The hardness of the weld bead obtained was in the range of 200-250 HV with base metal having nearly same hardness value. Bharwal et al. [24] reported 610 MPa as maximum tensile strength that was obtained for 6mm thick SS202 sheets at 160A current, 6 L / min flow rate of shielding gas and at 2.5mm/sec welding speed by MIG welding process. Singh et al. [25] carried out MIG welding on SS202 and SS304 sheets using 3 different level of current,

voltage, and shielding gas flow rate. Welding voltage showed most significant effect on the Tensile strength. Shielding gas flow rate, welding input current, and welding speed are the most extreme factor affecting the properties and quality of the welded bead. [26]. Kannan et al. [27] investigated the effect of single process variable that is Arc Length Correction (ALC) factor on the weld bead of AISI 316L low carbon austenitic stainless steel of 2mm thickness using ER 316L filler wire by CMT welding process. The tensile strength of welded joint showed a rise when the correction factor increased from 0% to 20 % and the optimum quality weld bead profile was obtained at 10 % ALC factor.

Analysis of Weldability of SS202 has been always a domain of research in all these years because of above mentioned characteristics and applications. Many researchers have analyzed the weldability of SS202 materials as discussed above using MIG, TIG, and other arc metal welding process. In this paper three independent process parameter current, welding speeds, and pulse dynamic correction factor is taken into account and SS202 plates of thickness 1.58 mm are welded using CMT welding process. Out of three process parameter current and welding speed directly affect the heat input and already discussed by various researchers in past. The third process parameter pulse dynamic correction factor is provided in CMT welding machine to slow down or accelerate the droplet detachment at a constant energy level. The pulse dynamic correction factor controls the average current and influences the direct current [28] For correcting the pulsing energy of a pulsed arc Pulse dynamic correction factor can be set at 3 different levels, that are -10, 0, and +10 wherein -10 represents that detachment force for the droplet is on lower side, 0 represents that there is no increase or decrease in the droplet detachment force and +10 represents that force for detaching the droplet is on the higher side. Three different level of current 80A, 100A, 120A, welding speed 3mm / sec, 4mm / sec, 5mm / sec and Pulse dynamic correction factor -10, 0, +10 were fixed and the most optimum combination of process parameter were obtained by Taguchi L9 design of experiment array using MINITAB 19 software. Value of Yield Strength, Ultimate Tensile Strength, and Percentage Elongation was found using TINIUS OLSEN ULTIMATE TESTING MACHINE H50KS of 50 KN. Further, Taguchi S / N ratio optimization tool based on Larger the better criteria was applied on the experimental values obtained by using MINITAB 19 software to get the most optimized parametric combination so as to obtain the best value of the three properties stated above both individually and simultaneously.

2. EXPERIMENTAL PROCEDURE

2.1. Materials and Methods

Experimental trials were carried out on SS202 plates of dimension 100mm × 60mm × 1.58mm. The chemical composition (% wt.) of SS202 base plate is mentioned in Table 1 below. SS308 electrode wire of 1.2 mm diameter was used as filler wire which is having compatible composition and mechanical characteristics as SS202 [29]. The samples were welded by cold metal transfer welding process using TPS 400i CMT welding machine (by Fronius) as displayed in Figure 1. A shielding gas with 98 % argon and 2 % CO₂ composition was used for conducting the experiment. Liao M.T. et al. [30] reported that shielding gas shelter the welded pool from atmospheric gases (e.g. oxygen and nitrogen) which influences the microstructure of the stainless steel weldment. Increasing the CO₂ percentage in the mixture of Argon and CO₂ increases the carbon content in weld deposits along with increasing the spatter rates.

Figure 1: Experimental-Setup.

Table 1: Chemical Composition (% Wt.) Of SS 202 Base Plate Material

Material	Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Co	Cu
SS 202	73.9	0.103	0.490	10.5	0.0730	0.0179	12.8	0.303	0.205	0.0279	1.39

2.2. Process Parameter

After in depth analysis of published work three independent processes Parameter Current, Welding Speed and Pulse dynamic correction factor were set for first few trial experiment. The weld bead and plates after each trial run was analyzed visually to check for the burn through and distortions of the base plates. Finally, three different optimized values were obtained for each process parameter. Contact tip to work distance (CTWD) and shielding gas flow rate were kept constant at 10mm and 15 L / min for each experiment respectively. Using Taguchi's Design of experiment best optimized parametric combination of process parameter using MINITAB 19 Software was found. Based on Taguchi's L9 design of experiment array total nine parametric combinations had been designed using three different levels of Pulse dynamic correction factor, current and welding speed. Table 2 shows the values of three different welding process parameter and their levels. In this paper the symbol C is used for Current, S for welding speed and P for Pulse dynamic factor. Actual value of process parameter based on Taguchi's design of experiment array is displayed in Table 3.

Figure 2: CMT Welded SS 202 Sample 1 (*S-1).

Table 2: Value of Process Parameter and Their Levels Based on Taguchi's Design of Experiment

Process Parameter	Welding Current	Welding Speed	Pulse Dynamic Correction Factor (PDC)
Unit	Ampere	Mm / sec	N / A
Symbols	C	S	P

Level 1	80	3	-10
Level 2	100	4	0
Level 3	120	5	+10

Table 3: Taguchi's L9-Orthogonal Array with Actual Value of Process Parameters

Sample No	Welding Process Parameter		
	Welding Current (A)	Welding Speed (Mm / Sec)	Pulse Dynamic Correction Factor (PDC)
1	80	3	-10
2	80	4	0
3	80	5	+10
4	100	3	0
5	100	4	+10
6	100	5	-10
7	120	3	+10
8	120	4	-10
9	120	5	0

Figure 3: Image of All the 9 Samples Welded By CMT Welding Process (*S-Sample).

3. RESULTS AND DISCUSSIONS

Welded samples are shown in Figure 2 and Figure 3. From the welded samples optimum size specimens as shown in Figure 4 were cut with specific dimensions using wire cut EDM process with reference to ASTM standard. The Yield Strength (YS), Ultimate Tensile Strength (UTS), and Percentage Elongation value of the welded specimens were determined using TINIUS OLSEN UTM H50KS of 50 KN by applying load at fixed extension rate. Table 4 shows the value of three for all the 9 samples at different process parameters. Gautam et al. [29] reported maximum tensile strength of 800 MPa for SS202 welded sample using GMAW process. In this study from the experimental result highest tensile strength of 871 MPa for sample 8 was obtained at process parameter C3S2P1 (at 120A Current, 4 mm / sec Welding Speed and -10 Pulse dynamic factors). Kannan et al. [27] reported maximum Yield strength of 221 MPa for cold metal transfer welded 2mm thick austenitic stainless steel sheets. Maximum Yield Strength and Percentage elongation for MIG welded austenitic stainless steel sheets of 3mm as reported by Ghosh et al. [31] were 322.7 MPa, and 65.04 % respectively. In this study superior value of yield strength of 379 MPa for the sample 2 was recorded at C1S2P2 process parameter (at 80A Current, 4mm / sec Welding Speed and 0 Pulse dynamic factor) and maximum percentage elongation of 65.9 % was recorded for sample 8 at process parameter C3S2P1 (at 120A Current, 4 mm / sec Welding Speed and -10 Pulse dynamic factor). The welding efficiency was found to be more than 100% as tensile strength of the SS202 parent sample [32-33] is low as compared to tensile strength obtained for the welded

sample as discussed above. The stress-strain curve for the CMT welded samples is shown in Figure 5. Percentage elongation indicates the tensile ductility of the material [34]. All the welded samples showed more than 50 % percentage elongation and maximum yield strength of 379 MPa. Value of yield strength which is determined at 0.2 % offset or 0.2 percent strain is important in the engineering application where deflection is considered. [35].

Figure 4: Test Specimens for Tensile Testing (*S-Sample).

Table 4: Process Parameter and Response Table for All the 9 Samples

Sample No	Welding Process Parameter			Responses		
	Current (A)	Speed (Mm / Sec)	Pulse Dynamic Correction Factor (PDC)	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	Percentage Elongation (%)
1	80	3	-10	807	204	54.4
2	80	4	0	817	379	58.8
3	80	5	+10	750	260	52.4
4	100	3	0	860	365	59.8
5	100	4	+10	742	279	50.8
6	100	5	-10	782	198	53.2
7	120	3	+10	763	217	50.4
8	120	4	-10	871	209	65.9
9	120	5	0	807	149	64.4

Figure 5: Typical Stress-Strain Curve for Welded Samples.

3.1. Optimization and Analysis of Yield Strength (Ys) Ultimate Tensile Strength (UTS), and Percentage Elongation by Taguchi Method:

The experimental results were analyzed by Taguchi's Method using MINITAB 19 software. Signal-to-Noise (S / N) ratio is a numerical measure of performance taking both average and inconsistency into account used in the Taguchi method [31].

There are three typical S / N ratios that are used and evaluation is done based on the requirement of the process or product to be optimized. The three different S / N ratio are:

- Smaller –the-better:

$$S/N \text{ ratio} = -10 \log_{10} \frac{1}{n} \sum_{i=1}^n Y^2 \quad (1)$$

- Nominal-the-best:

$$S/N \text{ ratio} = -10 \log_{10}(s^2) \quad (2)$$

- Larger-the-better:

$$S/N \text{ ratio} = -10 \log_{10} \frac{1}{n} \sum_{i=1}^n \frac{1}{Y^2} \quad (3)$$

where Y = value of responses obtained experimentally for every factor-level combination, n is the no. of responses, s is the standard deviation of n number of observation. To get the maximum value of Tensile Stress, Yield Stress and Percentage Elongation Larger-the-better S/N ratio criteria was used. S/N ratios for ultimate tensile strength using larger the better criteria are mentioned in Table-5. Figure 6 shows that most optimum parametric combination for obtaining maximum ultimate tensile strength is C3S1P2 that is level-3 for current, level-1 for speed and level-2 for Pulse dynamic correction factor (that is 120A current, 3 mm/sec speed and 0 Pulse dynamic correction factor). Table 6 displays response table for S/N ratios for Maximum Yield Stress using larger the better criteria. Figure 7 shows the most optimum value of respective process parameter for obtaining maximum yield stress. Most optimum parametric combination is C2S2P2 that is level-2 for current, level-2 for speed and level-2 for Pulse dynamic correction factor (that is 100A current, 4 mm/sec speed and 0 Pulse dynamic correction factor). Table 7 displays response table for S/N ratios for Maximum Percentage elongation using larger the better criteria. From Figure 8 it can be concluded that most optimum process parameter for obtaining maximum value of percentage elongation is C3S2P2 that is Level-3 for current, level-2 for welding speed and level-2 for Pulse dynamic correction factor (that is 120A current, 4 mm/sec speed and 0 Pulse dynamic correction factor). Table 8. Displays response table for S/N ratio considering Maximization of Yield Strength (YS), Ultimate tensile strength (UTS), and Percentage Elongation. Figure 9 displays that for obtaining most optimum value of three simultaneously for a single sample the most optimized process parameter is C3S2P2 that is Level-3 for current, level-2 for welding speed and level-2 for Pulse dynamic correction factor (that is 120A current, 4 mm/sec speed and 0 Pulse dynamic correction factor). Current shows highest ranking for Yield Stress. Pulse dynamic correction factor showed highest ranking for Ultimate tensile strength and Percentage elongation. As high value of Pulse dynamic correction factor results in low value of detachment current and hence low heat input, and low value of Pulse dynamic correction factor results in larger detachment current value and hence more heat input [28]. At 0 Pulse dynamic correction factor most significant results were reported as discussed above, which indicates both fast and slow rate of droplet detachment at constant energy level affects the weld bead properties.

Table 5: Response-Table for S / N Ratios for Maximum Ultimate Tensile Strength (UTS)

Level	Current (A)	Welding Speed (Mm/ Sec)	Pulse Dynamic Correction Factor (PDC)
1	57.96	58.16	58.27
2	57.99	58.15	58.36
3	58.20	57.83	57.52
Delta	0.24	0.33	0.84
Rank	3	2	1

Figure 6: Mean S / N Ratio Graph for Ultimate Tensile Strength (UTS).

Table 6: Response-Table for S/N Ratios for Maximum Yield Stress (YS)

Level	Current (A)	Welding Speed (Mm / Sec)	Pulse Dynamic Correction Factor (PDC)
1	48.69	48.06	46.18
2	48.70	48.96	48.76
3	45.53	45.90	47.98
Delta	3.17	3.06	2.58
Rank	1	2	3

Figure 7: Mean S / N Ratio Graph for Yield Stress (YS).

Table 7: Response-Table for S/N for Maximum Percentage Elongation

Level	Current (A)	Welding Speed (Mm / Sec)	Pulse Dynamic Correction Factor (PDC)
1	34.83	34.76	35.20
2	34.72	35.29	35.70
3	35.53	35.03	34.18
Delta	0.81	0.53	1.52
Rank	2	3	1

Figure 8: Mean S/N Ratio Graph for Percentage Elongation

Table 8: Response-Table for S/N Ratios for Maximum Yield Strength (MPa), Ultimate Tensile Strength (MPa), Percentage Elongation (%)

Level	Current (A)	Welding Speed (Mm/Sec)	Pulse Dynamic Correction Factor (PDC)
1	39.39	39.30	39.62
2	39.29	39.83	40.13
3	39.82	39.37	38.76
Delta	0.54	0.52	1.37
Rank	2	3	1

Figure 9: Mean S/N Ratio Graph For Yield Strength (Mpa), Ultimate Tensile Strength (Mpa), Percentage Elongation (%).

4. CONCLUSIONS

- Weld bead of SS202 sheets of thickness 1.58 mm when welded by CMT Welding process showed excellent weldability and satisfactory Yield Strength, Ultimate tensile strength, and Percentage elongation.
- From experimental results maximum values of Yield Strength, Ultimate Tensile Strength, and Percentage Elongation obtained were 379 MPa, 871 MPa, and 65.9 % respectively.
- From Taguchi S/N ratio larger the better criteria, most optimum combination of process parameter for obtaining maximum:
- Ultimate Tensile Strength value is C3S1P2 that is at 120A current, 3 mm/sec welding speed and 0 Pulse dynamic correction factor.
- Yield Strength value is C2S2P2 that is at 100A current, 4 mm/sec welding speed and 0 Pulse dynamic correction factor.
- Percentage Elongation value is C3S2P2 that is at 120A current, 4 mm/sec speed and 0 Pulse dynamic correction factor.
- From Taguchi S/N ratio higher the better criteria, most optimum combination of process parameter for obtaining maximum Yield Strength (YS), Ultimate tensile strength (UTS), and Percentage Elongation simultaneously for a single sample is C3S2P2 that is at 120A current, 4 mm/sec speed and 0 Pulse dynamic correction factor.
- At 0 Pulse dynamic correction factor most significant result were reported by Taguchi S/N ratio larger the better criteria, as discussed above in conclusion 3 and 4, which indicates both fast and slow rate of droplet detachment at constant energy level affects the weld bead properties.

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