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Materials Today: Proceedings XX (2016) XXX–XXX

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PMME 2016

☆ Parametric Optimization of Gas metal arc welding process by PCA based Taguchi method on Austenitic Stainless Steel AISI 316L

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Abstract

In the present work AISI 316L stainless steel samples have been welded by MIG welding. Butt joints have been made. Plate thickness is kept constant (= 3mm). Some important parameters have been varied during welding. Thus several butt-welded joints have been made. Each sample of the joints has been prepared under certain combination of welding parameters. The parameters considered for variation, in the present work have been welding current, gas flow rate and nozzle to plate distance. The design of experiment has been done using L9 Taguchi design of experiment. The influence of the process parameters (mainly current, gas flow rate and nozzle to plate distance) has been examined visually and also through X-ray radiographic tests. Next, samples have been cut, machined to conform to some specified dimensions for tensile testing. The quality of the weld has been evaluated in terms of ultimate strength, yield strength and percentage of elongation of the welded specimens. The observed data have been interpreted, discussed and analyzed by using principal component analyses (PCA). Optimum parametric setting has been predicted and validated as well. Useful interpretations of the experimental results and subsequent analysis have been made to draw some meaningful conclusions.

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Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

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Keywords: MIG Welding, X-ray Radiographic Test, Tensile Test, Principal Component Analyses

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1. Introduction

The S.S 316L is a chromium-nickel-molybdenum austenitic stainless steel developed to provide improved corrosion resistance to S.S 304/304L in moderately corrosive environments. The addition of molybdenum improves general corrosion and chloride pitting resistance. 316stainless steel is selected over other materials because of its distinct properties, cheaper cost and its availability in the market. 316stainless steel used is a boiler grade steel used in pressure vessels. This grade has high corrosion resistance and can be operated at elevated temperature. Type 316 stainless steel is widely used in application requiring corrosion resistance superior to Type 304, or good elevated temperature strength. Typical uses include exhaust manifolds, furnace parts, heat exchangers, jet engine parts, pharmaceutical and photographic equipment, valve and pump trim, chemical equipment, digesters, tanks, evaporators, pulp, paper and textile processing equipment. Gas Metal Arc Welding is a process in which the source of heat is an arc format between consumable metal electrode and the work piece with an externally supplied gaseous shield of gas either inert such as argon, helium[2]. Weld quality mainly depends on features of bead geometry, mechanical-metallurgical characteristics of the weld as well as on various aspects of weld chemistry and these features are expected to be greatly influenced by various input parameters like current, voltage, electrode stick-out, gas flow rate, edge preparation, position of welding, welding speed and many more [3,4]. Moreover, the cumulative effect of various input parameters determines the extent of joint strength that should meet the functional aspects of the weld in practical field of application. Therefore, preparation of a good quality weld seems to be a challenging job. The welding investigators have always been in search for better quality of weldment

E.taban et al. [1] investigated the microstructural and toughness properties and mechanical properties of Dissimilar Welds joints between Ferritic Stainless Steel Modified 12% Cr and Carbon Steel S355. **E. taban et. al** [5**]** also studied the properties of a modified 12% Cr ferritic stainless steel were evaluated when welded with three different consumables and finally they recommended to use 309 and 316 welding wires for better corrosion resistance compared to 308 welding wires **. M. Mukherjee and T.K. Pal** [6] studied the Influence of Heat Input on Martensite formation and impact property of Ferritic-Austenitic Dissimilar Weld metals**.**

2. Experimental Plan, Set - up And Procedure

In the present work, experiments are done in a planned experimental order Taguchi Orthogonal array design L9 has been used as design of experiment. Welding current, gas flow rate and nozzle to plate distance are selected as input parameters and three levels are considered for each of them. Welding process parameters and their levels are shown in Table 1**.**Welding Design Matrix as per L9 Taguchi Orthogonal Array Design is shown in Table 2.

Table1.Welding process parameters and their levels

	UNIT	**NOTATION**	**LEVELS**		
FACTORS			**1**	**2**	**3**
Welding Current	A	C	100	112	124
Gas Flow rate	*l*/min	F	10	15	20
Nozzle to Plate Distance	mm	S	9	12	15

Table 2.Welding Design Matrix as per L9 Taguchi Orthogonal Array Design of matrix

Welding Current (A)	Gas flow rate(*l*/min)	Nozzle to plate distance (mm)
1	1	1
1	2	2
1	3	3

2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

Butt joints between austenitic stainless steel AISI 316L each of dimension 100mm x 65mm x 3mm are joined by MIG welding process by using austenitic filler wire AISI 316 L . No edge preparation is used as it is not recommended for welding of 3 mm thick austenitic stainless steel. Diameter of the electrode wire is selected 1.2 mm.

Welding has been done on ESAB make AUTO K -400 MIG/MAG welding machine. Butt welded joints being done under varied input parameters, visual inspection and X-ray radiographic test of all welded specimens has been made. After visual inspections and X-ray radiographic test, tensile test specimens have been prepared from the welded joints, by cutting/machining.

X-ray radiographic test has been carried out for all nine samples. The copies of few radiographic films are shown in Fig.1 –Fig.2 respectively

Fig1. Copies of X-ray Radiographic Film For Sample No-4

Fig2. Copies of X-ray Radiographic Film For Sample No-5

3. Tensile Test Results And Discussion

The tensile test specimens, prepared corresponding to L_9 Taguchi Orthogonal Array design of experiments, have been tested for tensile strengths and the results obtained are given in table 3**.**

Table 3.Tensile tests result as per L9 Taguchi Orthogonal Array Design of experiment

SAMPLE NO.	YIELD STRENGTH (MPa)	ULTIMATE TENSILE STRENGTH(MPa)	PERCENTAGE OF ELONGATION (%)
BASE PLATE	**301.6119**	**573.7524**	**65. 048**
1	321.1262	550.0938	31.212
2	317.9749	552.0211	34.643
3	322.7427	591.1774	54.539
4	288.8381	518.2146	33.023
5	250.227	432.3345	18.53
6	264.2308	481.4142	33.072
7	242.4277	426.2334	19.524
8	246.7417	484.9734	42.774
9	233.0469	450.9941	28.403

The **Table 3** indicates that for many of the welded samples test results are satisfactory. The best result is obtained for the sample no.3 (Corresponding to current 100 A, flow rate 20 *l*/min and nozzle to plate distance 15 mm). For this sample yield strength= 322.7427MPa ultimate tensile strength =591.1774 MPa percentage of elongation =54.539. The worst result in tensile testing has been obtained for the sample no. 7 (corresponding to current 124 A, gas flow rate 10 *l*/min and nozzle to plate distance 15mm). For this sample yield strength= 242.42773and ultimate tensile strength = 426.23343MPa and percentage of elongation =19.524

4. Optimization by Using Principal Component Analyses

Experimental data (Table 3) has been normalized first. The objective is to maximize the experimental data. For this purpose Higher-the-Better (HB) criteria is used. Data has been normalized using the equations shown below.

(a) LB (lower-the-better)

$$X_i^*(k) = \frac{\min X_i(k)}{X_i(k)} \qquad \text{eq.(1)}$$

(b) HB (higher-the-better)

$$X_i^*(k) = \frac{X_i(k)}{\max X_i(k)}$$

$$i = 1,2,\ldots\ldots,m;$$

$$k = 1,2,\ldots\ldots,n \qquad \text{eq.(2)}$$

$X_I^*(k)$is the normalized data of the *k th* element in the *i th* sequence
Normalized experimental data is shown in Table 4.

Table 4. Normalized Experimental Data

Sl. NO.	Yield Strength(MPa)	Ultimate Tensile Strength(MPa)	Percentage of elongation(%)
1	0.9949	0.9305	0.5722
2	0.9852	0.9337	0.6352
3	1.0000	1.0000	1.0000
4	0.8949	0.8765	0.6054
5	0.7753	0.7313	0.3397
6	0.8187	0.8143	0.6063
7	0.7511	0.7209	0.3579
8	0.7645	0.8203	0.7842
9	0.7220	0.7628	0.5207

After data normalization a check has to be made whether responses are correlated or not. Table 5 represents Pearson's correlation coefficient between the responses. In all cases non-zero value of correlation coefficient indicates that all response features are correlated to each other.

Table 5. Correlation matrix (Pearson (n)):

Variables	Yield Strength	Ultimate Tensile Strength	Percentage of elongation
Yield Strength	**1**	0.944	0.625
Ultimate Tensile Strength	0.944	**1**	0.836
Percentage of elongation	0.625	0.836	**1**

Results of PCA (Eigen value, Eigen vector, accountability proportion AP and cumulative accountability proportion CAP) is shown in Table6.

Table6. Eigen value, Eigen vector, accountability proportion AP and cumulative accountability proportion CAP).

	ψ_1	ψ_2	ψ_3
Eigen Values	2.5138	0.4798	0.0064
Eigen vector	0.574 0.627 0.527	-0.596 -0.121 0.794	-0.562 0.769 -0.304
AP	0.838	0.160	0.002
CAP	0.838	0.998	1.000

Finally, multi-response performance index (MPI) has been computed using the following equation MPI= ψ_{1}*0.838 + ψ_{2}*0.160 + ψ_{3}*0.002. MPI has been treated as single objective function for optimization in order to maximize it. The factorial combination that maximized MPI can be treated as optimal parametric combination/ most favorable process environment ensuring high surface quality. This has been performed using Taguchi method.

Table 7. Principal Components And Calculated MPI

Sample No.	yield strength (Mpa)	Ultimate tensile strength(Mpa)	percentage of elongation (%)	calculated MPI
1	1.456	-0.251	-0.018	1.179
2	1.485	-0.196	-0.028	1.213
3	1.728	0.077	-0.097	1.461
4	1.382	-0.158	-0.013	1.132
5	1.082	-0.280	0.023	0.862
6	1.300	-0.105	-0.018	1.072
7	1.072	-0.251	0.023	0.858
8	1.366	0.067	-0.037	1.155
9	1.167	-0.109	0.023	0.961

Figure 3 represents S/N ratio plot of MPI; S/N ratio has been calculated using Higher-the-Better (HB) criteria. Optimal setting has been evaluated from this plot. Predicted optimal combination becomes: C1F3S1. Optimal result has been verified through confirmatory test. According to Taguchi' prediction , predicted value of S/N ratio for MPI becomes 2.9976 whereas in confirmatory experiment it is obtained a value of 3.2930. So quality has improved using the optimal setting.

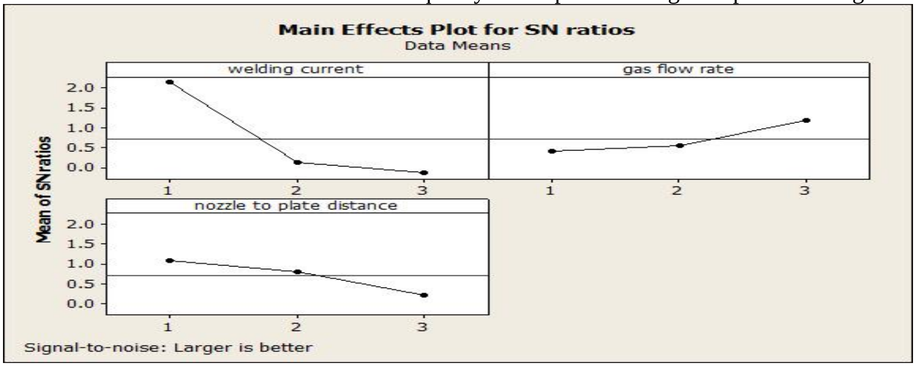

Figure 3 represents S/N ratio plot of MPI

5. Conclusions

- Best result is obtained for the sample no.3 (Corresponding to current 100 A, flow rate 20 *l*/min and nozzle to plate distance 15 mm). For this sample yield strength= 322.7427MPa ultimate tensile strength =591.1774 MPa percentage of elongation =54.539. The worst result in tensile testing has been obtained for the sample no. 7 (corresponding to current 124 A, gas flow rate 10 *l*/min and nozzle to plate distance 15mm). For this sample yield strength= 242.42773and ultimate tensile strength = 426.23343MPa and percentage of elongation =19.524
- With the help of mean main effect plots and S/N ratio plots, optimum parametric combination has been determined. The optimal factor setting becomes **C1F3S1** (i.e. welding current=100A, Gas flow rate = 20*l*/min and Nozzle to plate distance =9mm)

6. References

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