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Application of Taguchi Method for Optimization of Tensile Strength of Shielded Metal Arc Welding (SMAW) Process for Steel SA 516 Grade 70

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Abstract - In present study the effects of Shielded Metal Arc Welding (SMAW) parameters on analysis of tensile strength on SA 516 grade 70 was performed. SA 516 grade 70 is commercially used for manufacturing boilers. Analysis was performed at three levels of welding speed, root face and welding current were varied on to determine their effect on tensile strength at room temperature. The experiments were designed using Taguchi L_9 orthogonal array, performed. Taguchi signal-to-noise ratio was applied for single objective optimization and to observe significant control parameters and optimal levels that improved tensile property. Analysis of variance showed that welding speed as most significant parameter with contribution of 69% followed by welding current and root face, respectively.

Keywords - Taguchi, SA 516 Grade 70, Tensile Strength, Orthogonal Arrays, Optimization.

I. Introduction

Steel is material for high tensile strength and considerable toughness. Shielded Metal Arc Welding (SMAW) is commonly used joining process for the fabrication of variety of products such as pressure vessels, machines, boilers, etc. SMAW results in good quality when employed for pressure vessels [1]. Commercially. SMAW is most versatile source of heat in practice and widely used in welding of steel sections [2]. SMAW is joining process for metals [3]. Welding is of good quality when deposition rate is maximum [4].

Manufacturing of steel structures involve welding as an important phase and fundamental. Oil and gas sector cause their proper functionality due to welding defects that are cause of crack [5, 6]. SA 516 grade 70 is low carbon steel as material for boiler due to good mechanical properties at working temperatures. These steels have wide applications in steam generating plants, super heater tubes and piping. Analytical and experimental design techniques have been used for analyzing relationship among quality characteristics and process parameters [7].

Local industry is facing the problem of identification and control of input process parameters to obtain a good weld quality joint and use trial and error method that is an error based. This research is aimed at identifying the parameters effecting tensile strength steel SA 516 Grade 70 on Shielded Metal Arc Welding.

II. Literature Review

concepts of Design of Experiments introduced by Fisher in 1920 [8]. Rohit et. al., attempted to study the effect of varying current on ultimate tensile strength (UTS) of SMAW weld joint. It was concluded that increase in welding current up-to a certain limit will improve UTS and beyond optimal current value increasing current deteriorates UTS [9]. Shukla et. al., developed regression models for prediction of quality characteristic on the application of SMAW to join AISI 1020 low carbon steel plates using full factorial design and response surface methodology (RSM).

Proposed study aimed at optimizing the effect of torch angle, electrode polarity and welding current on penetration depth during SMAW process [10].

Patel et. al., applied Taguchi method for investigation of MIG welding process parameters effect on AISI 1030 and welding speed (mm/min) and welding current (A) were found to be significant parameters [11]. Ajit et. al., optimized TIG welding process on SS-304 to achieve maximum tensile strength by employing statistically designed L_9 taguchi orthogonal arrays and Taguchi method. Gas flow rate, welding speed and welding current were selected parameters each at three levels. ANOVA was applied to find percentage contribution of parameters [12].

Kumanan et. al., applied optimization technique genetic algorithm for determining optimal welding parameters that results in minimization of weld bead [13].Numerous research groups employed various methods and techniques with aim to optimize steel welded structures, such as mechanical properties improvement and defects reduction [14, 15]. Several investigators [16-18] employed ANOVA for finding significant factors and their percentage contribution.

III. Parameters

The welding parameters investigated in this study are root face, welding current as well as welding speed are depicted in Table 1.

3.1 Welding Current: It is the most prominent welding parameters that controls weld metal deposition rates, width and depth of penetration, depth of fusion, and electrode feed rate. Therefore, it is very critical to use right amount of current to manufacture sound quality of welded joint and minimize distortion issues. Setting of current level is directly proportional to the amount of heat produced for a given electrode size and thickness of plate. Lower welding current results in difficulties in stabilizing arc.

3.2 Welding Speed: Welding speed is defined as the rate at which electrodes passages along the trajectory of weld joint in welding direction. Increase in welding speed cause increase in heat input per unit area and then decreases. Very welding speed cause lack in deposition rates of filler metal and results in defective welding.

3.3 Root Face: The vertical surface of groove that is attached to root of welded joint. If no face is designed in joint, then it is called root edge. Root face is exposed surface from is welding is initiated. It is necessary for the welding engineer to main root face thick to fuse the weld metal. If the root face is inadequate, metal will spill out of joint.

Table 1 Welding Parameters

Parameters	Level 1	Level 2	Level 3
Welding Speed (mm/s)	2	3	4
Welding Current (A)	100	120	140
Root Face (mm)	2	3	4

IV. Experimentation

In this research work two plates of graded steel ASME SA 516 Grade 70 having strength of 462 MPa and dimensions 125 mm x 130 mm x 14 mm, plates are welded using Shielded Metal Arc Welding (SMAW) in Pakistan. The chemical composition of ASME SA 516 Grade 70 is shown in Table [19].

Table 2 Chemical Composition of ASME SA 516 Grade 70

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Nb	B	V	N	Cu	Ti
% Value	0.222	0.32	1.12	0.013	0.007	0.048	0.006	0.012	0.018	0.014	0.002	0.005	0.001	0.006

Sides plates of ST-37 material are joined with no special pre or post weld heat treatment were applied. Nine sample of dimensions 250mm x 130mm x 14mm were made. Experiments focus on changing in mechanical properties Experiments are performed based on Taguchi orthogonal arrays obtained from Minitab 16. Taguchi orthogonal array in coded and un-coded forms are shown in Table 2 and Table 3.

Table 3 Taguchi Design Matrix in Coded Form

S. No	Welding Current	Welding Speed	Root Face
1	1	1	1

2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Nine experiments were performed to study effect of three welding parameters on Tensile strength using L_9 orthogonal array. Numerous Researchers [16-18] applied Taguchi method for single objective optimization. Larger-the- Better criteria is selected for signal-to-noise ratio for tensile strength [20-22] by using the logarithmic function

$$S/N = -10 \log_{10} \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2}$$

Where n are number of experimental observations and y_i are the observations. Calculated S/N ratios for experimental trail are depicted in Table 4.

Table 4 Design Matrix included Experimental values and S/N Ratios

S. No	**Welding Current (A)**	**Welding Speed (mm/s)**	**Root Face (mm)**	**Tensile Strength (N/mm^2)**	**S/N Ratio of Tensile Strength**
1	100	2	2	519	54.30
2	100	3	3	562	54.99
3	100	4	4	560	54.96
4	120	2	3	535	54.57
5	120	3	4	578	55.23
6	120	4	2	603	55.60
7	140	2	4	490	53.80
8	140	3	2	558	54.93
9	140	4	3	554	54.87

Table 5 Response Table for Parameters

Level	**Welding Current**	**Welding Speed**	**Root Face**
1	54.75	54.22	54.95
2	55.14	55.06	54.81
3	54.54	55.15	54.67
Delta	0.6	0.92	0.28
Rank	2	1	3

From Table 5, it is evident that welding speed is most significant parameter. Further, Normal probability plot shown that whole data lies within 95 % confidence interval .

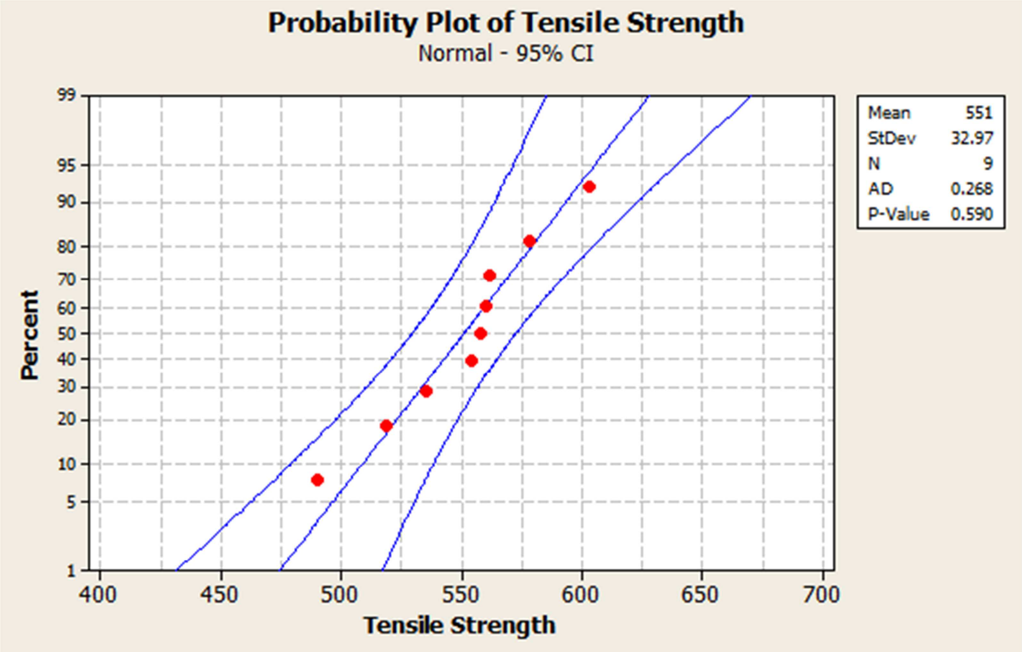

Figure 1 – Normal Probability Plot for Tensile Strength

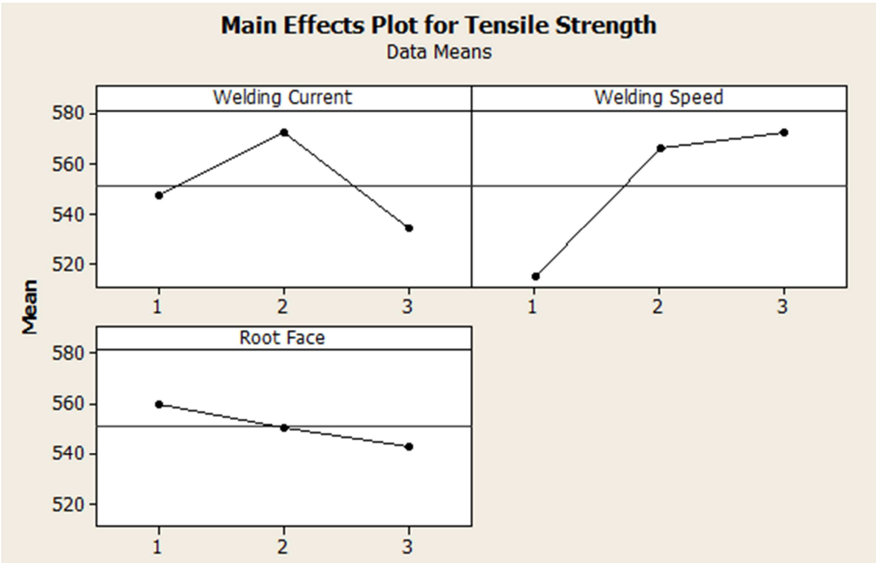

Figure 2 – Main Effects Plot for Tensile Strength

The main effects plot revealed that highest value of tensile strength obtained medium level of welding current and increased in welding speed results in increased tensile strength. Further, as root face increases, tensile strength decreases.

V. ANOVA

Analysis of Variance was employed to investigate significance of welding parameters on the response quality characteristic. ANOVA separates the total variability of experimental values that is calculated by sum of squared deviations from total mean of experimental values into contributions of SMAW welding parameters and error term [23].

Table 5 Analysis of Variance of Tensile Strength

Analysis of Variance for Tensile Strength							
Source	**DoF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**% Contribution**	**Remarks**
Welding Speed	2	6000	3000	2250	0.000	69.04	Most Significant
Welding Current	2	2238	1119	839	0.001	25.75	Significant
Root Face	2	452	226	170	0.006	5.2	Significant
Error	2	2.7					
Total	8	8694					
Model Summary							
R-Sq	99.98%	R-Sq (adj)	99.94%				

ANOVA calculations revealed that welding current is most significant parameter with contribution of 69%. Welding parameter having higher F value means large effect on quality characteristic.

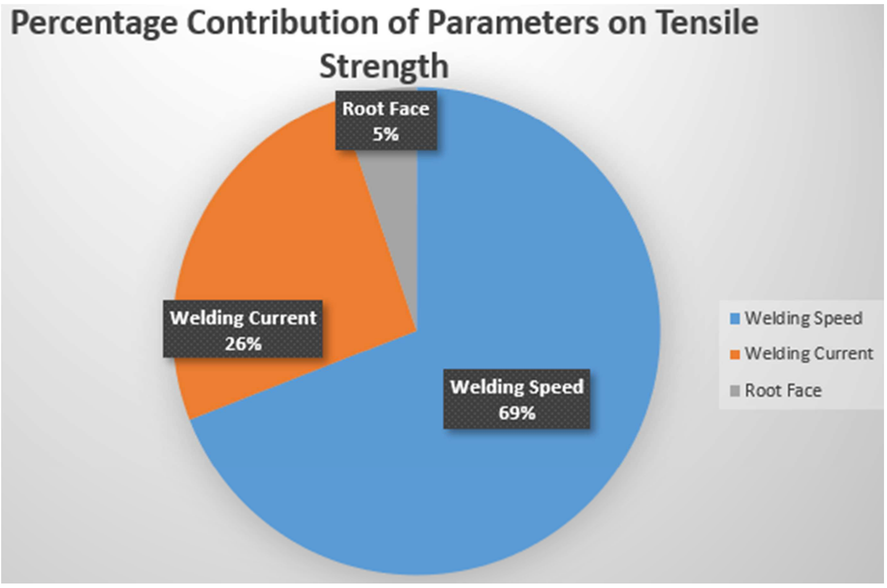

Figure 3 – Pie Chart of Parameters Effect on Tensile Strength

VI. Conclusions

SMAW was studied with focus of research is to improve tensile strength of SMAW joint process parameters i.e. welding current, root face and welding speed. Research work also focus to remove welding defects analyzing and optimizing welding effect on tensile strength. Taguchi method and ANOVA are employed for analysis and optimization. Findings of analysis are

1. It is found that increase in welding current has adverse effects on tensile strength. Further, at welding current of 100 A, the tensile strength (N/mm^2) was found to be maximum in comparison with 120 A and 140 A. It is also concluded that increase in welding current up-to a limit increase ultimate tensile strength (UTS) to a maximum value (optimum).

2. From ANOVA calculations, Response table for Parameters, and Pie Chart, it is found that welding speed as most significant parameter with percentage contribution of 69 % followed by welding current 26 % and root face 5 %.

3. Optimal settings are obtained at 120 A, welding speed 3 mm/s and root face 3 mm corresponding to sample 5.

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