

Models for selecting GMA Welding Parameters for Improving Mechanical Properties of Weld Joints

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Abstract: During the process of Gas Metal Arc (GMAW) welding, the weld joints mechanical properties are influenced by the welding parameters such as welding current and arc voltage. These parameters directly will influence the quality of the weld in terms of mechanical properties. Even small variation in any of the cited parameters may have an important effect on depth of penetration and on joint strength. In this study, S45C Constructional Steel is taken as the base metal to be tested using the parameters wire feed rate, voltage and type of shielding gas. Physical properties considered in the present study are tensile strength and hardness. The testing of weld specimen is carried out as per ASTM Standards. Mathematical models to predict the tensile strength and depth of penetration of weld joint have been developed by regression analysis using the experimental results.

Key words: *GMA welding, depth of penetration, regression analysis, joint strength*

Introduction

Gas metal arc (GMA) or metal inert gas (MIG) welding is a process in which the source of heat is an arc formed in between the work piece and a consumable metal electrode, and the arc and molten puddle are shielded by inert gas from exposure to the atmosphere. In order to achieve desired mechanical properties of the welded joints, the process parameters are to be selected carefully. The objective of the present study is to investigate the main parameters that affects the mechanical properties of welded joints of S45C steel and to develop mathematical models to predict the tensile strength of the weld joints.

Research into the correlation involving the welding process parameters and bead geometry begin in the mid-1900s and regression analysis was applied to welding geometry by Lee and Um [1]. In welding process, the penetration dependent on voltage, gas flow rate, current, travel speed, and wire diameter. Even a small change in any of the cited factors could have a major effect on the depth of penetration [2].

The welding current used in GMA welding has the maximum effect on the deposition rate, the weld bead size, shape and penetration. When all the other welding parameters are kept invariable, increase in the current will increase the depth of the weld penetration and bead width [3].

S45C steel plate is one main medium carbon steel, which is suitable for structures, buildings and marine application. It is available as rolled or normalized form. They are excelling in weld ability & machine ability, and they can be subjected to various heat treatments which are based on JIS G 4051-2009. This steel gives a minimum yield point of 460 Mpa in all structural shapes and in plates up to 8 inches thick [4].

Design of Experiments (DOE) Taguchi method and Fraction factorial experimental techniques have been generally used to conduct the experimental work. Regression analysis and other statistical



procedure have been used by the researchers to develop mathematical relationship between the welding process parameters and the output variables of the weld joint such as bead geometry [5, 6].

Experimental procedure

S45C Constructional Steel plates with dimension of 100mm X 50mm X 6mm are prepared for single V butt joint as shown in Figure 1. The single V groove is profiled about 2mm. The mechanical properties of weld joints are determined using UTM machine and weld bead depth is measured using metallurgical microscope. ER70S-6 was used as the filler wire, and S45C as the base metal. The comparison of chemical composition of the both material are shown in Table 1. Since the base metal with thickness of $6\text{mm} \pm 0.5\text{mm}$ are used, filler wire with diameter of 0.8mm was used. Welding parameters combination was identified by conducting feasibility study. The range of parameters selected for this study is as shown in Table 2.

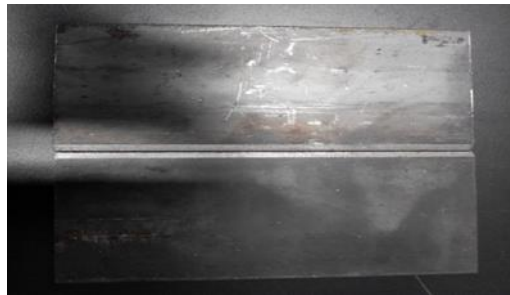


Figure 1. S45C Base Metal Single V Groove Profile

Table 1. Chemical composition of base metal and filler wire

Material	C	Mn	Si	S	P
JIS S45C	0.42 - 0.48	0.6 - 0.9	0.15 - 0.35	S < 0.035	< 0.03
ER70S-6	0.07	1.55	0.88	0.012	0.015

Table 2. Welding Input Parameters Design Matrix

Parameters	Unit	Notation	Factor Level		
			-1	0	1
Wire Feed Rate (WFR)	m/min	I	3.6	6.2	9.1
Welding Voltage	V	V	25	35	45
Type of Shielding Gas	-	G	-	CO ₂	Ar

The specimen for tensile testing is prepared by as per ASTM E8 as shown in Figure 2. Mathematical modeling by regression analysis is carried out using Minitab 17 statistical software.

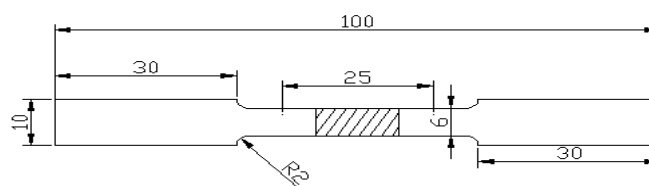


Figure 2. ASTM E8/E8M Specimen Dimension

Results and Discussion

During welding process, the weld bead of S45C steel appears irregular and porous with huge spatter with argon (Ar) as shielding gas. For carbon dioxide (CO₂) gas, there was minimum spatter during welding. When low voltage, low wire feed-rate, and CO₂ gas are used, the weld bead forms narrower and does not fill up the 'V' groove. The weld parameters, results of yield tensile strength and measured depth of penetration were tabulated as shown in Table 3. Type of Gas, 1 indicates CO₂ gas while 2 indicates Argon (Ar) gas.

Table 3. Experimental Design Matrix and Results

Run No.	Wire Feed Rate (WFR) m/min	Voltage V	Type of Gas (G)	Tensile Strength MPa	Depth of Penetration mm
1	3.6	25	1	187.348	1.87
2	6.2	25	1	227.926	2.21
3	9.1	25	1	190.971	2.43
4	3.6	35	1	119.527	2.21
5	6.2	35	1	208.923	2.00
6	9.1	35	1	221.844	2.00
7	3.6	45	1	120.36	2.50
8	6.2	45	1	137.001	2.00
9	9.1	45	1	201.229	1.53
10	3.6	25	2	219.969	1.80
11	6.2	25	2	14.885	1.56
12	9.1	25	2	268.673	1.91
13	3.6	35	2	81.44	2.49
14	6.2	35	2	163.068	1.89
15	9.1	35	2	249.799	2.11
16	3.6	45	2	125.758	2.61
17	6.2	45	2	42.206	2.58
18	9.1	45	2	100.398	1.50

Figure 3 and Figure 4 shows the correlation between the experimental values and the predicted values of tensile strength and depth of penetration respectively.

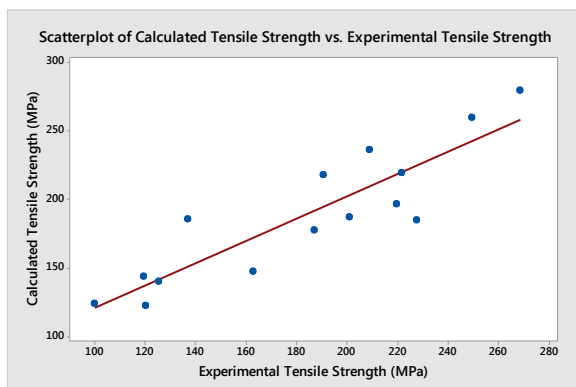


Figure 3. Tensile Strength Scatterplot

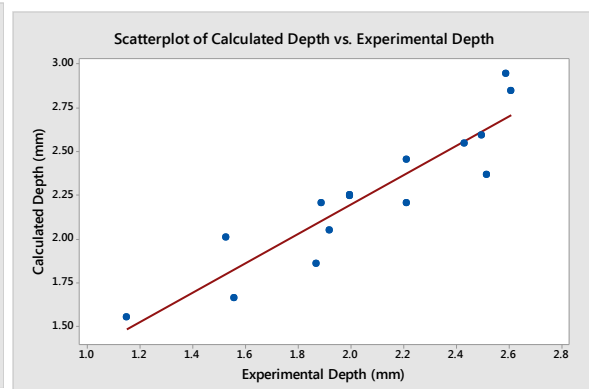


Figure 4. Depth of penetration Scatterplot

Since run number five (5), ten (10) and twelve (12) doesn't meet the expected or feasible result, the results of these specimens are removed from the regression analysis. Remaining experimental data obtained from design of experiments are used to develop mathematical model between input process parameters and tensile strength/depth of penetration. Regression analysis is carried out using MINITAB software, and optimized to achieve R^2 value within the range of 0.95 to 0.99

Regression equation is generated as general multiple linear model, which in the form of

$$Y = a + b_0 \cdot x_1 - b_1 \cdot x_2 + b_3 \cdot x_3 - b_4 x_1 \cdot x_1 + b_5 x_2 \cdot x_2 + \dots \quad \dots 1$$

Where

x_1 = Wire feed rate: x_2 = Voltage : x_3 =Type of gas

Y = output parameter (Tensile strength/ depth of penetration)

The equation resulted for tensile strength is

$$\begin{aligned} Y = & -196 x_1 - 14 x_2 + 1521 x_3 - 13.6 x_1 \cdot x_1 - 0.29 x_2 \cdot x_2 - 211 x_3 \cdot x_3 + 19.3 x_1 \cdot x_2 + 40 x_1 \cdot x_3 \\ & - 71.7 x_2 \cdot x_3 + 0.161 x_1 \cdot x_1 \cdot x_2 + 4.4 x_1 \cdot x_1 \cdot x_3 - 0.261 x_1 \cdot x_2 \cdot x_2 - 3.60 x_1 \cdot x_2 \cdot x_3 \\ & + 1.59 x_2 \cdot x_2 \cdot x_3 \end{aligned} \quad \dots 2$$

The resulting equation for depth of penetration is

$$\begin{aligned} Y = & 1.73 x_1 + 1.154 x_2 - 17.6 x_3 - 0.086 x_1 \cdot x_1 - 0.0137 x_2 \cdot x_2 + 10.2 x_3 \cdot x_3 - 0.048 x_1 \cdot x_2 \\ & - 0.53 x_1 \cdot x_3 - 0.706 x_2 \cdot x_3 + 0.00308 x_1 \cdot x_1 \cdot x_2 + 0.0027 x_1 \cdot x_1 \cdot x_3 - 0.00021 x_1 \cdot x_2 \cdot x_2 \\ & + 0.0129 x_1 \cdot x_2 \cdot x_3 + 0.00944 x_2 \cdot x_2 \cdot x_3 \end{aligned} \quad \dots 3$$

Analysis of Variance (ANOVA) is carried to verify the significant parameters effecting the output parameters viz., tensile strength and depth of penetration. It has been observed from the ANOVA table 4 and table 5 that wire feed rate and voltage has the significant effect on the output viz., tensile strength and depth of penetration. The ANOVA analysis tables shows that the shielding gas parameter has almost very less or no effect at all for both tensile strength and depth of penetration

Table 4. ANOVA Analysis of Depth of penetration Parameters

Source	DF	Adj SS	Adj MS	F-Value	P-Value
WFR	2	0.21149	0.105746	0.29	0.760
V	2	0.28091	0.140456	0.39	0.700
G	1	0.00045	0.000450	0.00	0.973
WFR*V	4	0.43916	0.109789	0.30	0.862
WFR*G	2	0.00701	0.003505	0.01	0.990
V*G	2	0.31967	0.159837	0.44	0.670
Error	4	1.44069	0.360172		
Total	17	2.69938			

Table 5. ANOVA Analysis of Tensile Strength Parameters

Source	DF	Adj SS	Adj MS	F-Value	P-Value
WFR	2	18864	9424	2.10	0.239
V	2	12928	6464	1.44	0.339
G	1	3119	3119	0.69	0.452
WFR*V	4	18400	4600	1.02	0.492
WFR*G	2	9720	4860	1.08	0.422
V*G	2	6247	3124	0.69	0.551
Error	4	18008	4502		
Total	17	87287			

Conclusions

The following conclusions can be made from the present work

- Mathematical model between tensile strength and welding parameters is developed to predict the tensile strength in single V butt joint
- Mathematical relationship between the depth of penetration and welding parameters is developed
- These models can be used to select the process parameters for the desired strength of butt joint

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