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Experimental study of shielded metal arc welding parameters on depth of penetration for aisi 1020 carbon steel using response surface methodology

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ABSTRACT

This paper focuses on the investigation of shielded metal arc welding parameter to maximize the Depth of penetratio using response surface methodology. Electrode polarity, welding current, and electrode angle was taken as input paramete while response was only one welding strength. Full Factorial was chosen for experimental design. RSM based model has been developed to determine weld strength by various welding parameter. The quadratic model developed using RSM shows high accuracy and can be used for prediction within limits of the factor investigated.

Keyword: *Stick welding, AISI 1020 (low carbon steel), depth of penetration, welding strength.*

1. Introduction

Shielded metal arc welding (SMAW) is one of the world's most popular welding processes, accounting for over half of all welding in some countries. Because of its versatility and simplicity, it is particularly dominant in the maintenance and repair industry, and is heavily used in the construction of steel structures and in industrial fabrication. In recent years its use has declined as flux-cored arc welding has expanded in the construction industry and gas metal arc welding has become more popular in industrial environments. However, because of the low equipment cost and wide applicability, the process will likely remain popular, especially among amateurs and small businesses where specialized welding processes are uneconomical and unnecessary.

Shielded metal arc welding is often used to weld carbon steel, low and high alloy steel, stainless steel, cast iron, and ductile iron. While less popular for nonferrous materials, it can be used on nickel and copper and their alloys and, in rare cases, on aluminum. The thickness of the material being welded is bounded on the low end primarily by the skill of the welder, but rarely does it drop below 1.5 mm (0.06 in). No upper bound exists: with proper joint preparation and use of multiple passes, materials of virtually unlimited thicknesses can be joined. Furthermore, depending on the electrode used and the skill of the welder, SMAW can be used in any position

The depth of penetration is one the major responses measured in all types of welding. Anyhow if the penetration is not proper the molten metal will appear with the cavity which reduces the endurance of the component and component will fail before its life .This will vanish everything which is involve in manufacturing of weldment whether metal ,time and money etc. Due to such problem depth of penetration plays an important role in weldment to increase its life and strength as well. Most of the researcher have payed a lot of attention in maximizing the depth of penetration of welded joints.Girolamo Costanza [1].

In this paper the author investigated the fusion welding of molten metal shielded from contact with the atmospheric gas by means of a gaseous flux. The shielding gas prevents weld embrittlement, affects welding quality, because of its influence on filler metal transfer, and has a direct impact on welding costs as well. Argon is the most common shielding gas, often used with some adds of other gases that can be inert, as helium, or active, as CO_2, O_2 or H_2. In this work the effects of mixtures with different composition have been considered for the arc welding of austenitic steels. Metallographic samples of welded sections have been undergone to visual and optical microscopy observations, microhardness, indentations and tensile tests. The AISI 304 and 316 sheets have shown a good weldability utilizing the electric arc and different compositions of the shielding gas (pure Ar or Ar plus He, H2, CO2 o r O 2). Satisfactory macrographic appearance with good penetration, right bead profile and absence of macroscopic defects has been observed.

Metallographic investigation on welded sections have shown the typical solidification structures and Vickers micro hardness tests have assessed the presence of hardened heat affected zones. As regard the homogeneity of the micro hardness profile across the welded sections, the best results have been obtained in the AISI 304 plates welded with Hydrostar H2, Hydrostar PB or pure argon as shielding gas (respectively samples 1, 5 and 6) which maintain hardness values not so different from the base material ones; while in the other cases micro hardeness peaks around 200 HV are reached. The welded zone is characterized by some lack of mechanical strength as pointed out by FIMEC and tensile test. In any case the joint efficiency results very high, particularly for AISI 316 plates welded with Hydrostar H2 or pure argon (respectively samples 2 and 7), where the efficiency achieves values around 90% for the ultimate stress. Kathersan et al. [2] studied the effect of FCAW welding parameters like wire feed rate, voltage, welding speed, torch angle using multiple regression analysis and experimental data in butt welding of AISI 316 plates. In this study, a regression model equation was developed using welding process parameters, to effectively control the weld bead width of a in FCAW welding.

The Taguchi method regression modeling are used in order to establish the relationship between input and output parameter. In the next stage the proposed model is embedded into PSO algorithm to optimize the FCAW process parameter. In this study the objective considered are maximization of depth of penetration and minimization of weld bead width and minimization of reinforcement .the best optimum result obtained are at F=9.5234, V= 23.7589,S = 5.5267, A=73.515, with response value of wire feed rate of 9.010 mm , reinforcement of 2.569 and penetration of 4.076. Izzatul et al [3] determine the effects of different parameters on welding penetration, microstructural and hardness measurement in mild steel that having the 6mm thickness of base metal by using the robotic gas metal arc welding are investigated. The variables that choose in this study are arc voltage, welding current and welding speed. The arc voltage and welding current were chosen as 22, 26 and 30 V and 90, 150 and 210 A respectively. The welding speed was chosen as 20, 40 and 60 cm/min. The penetration, microstructure and hardness were measured for each specimen after the welding process and the effect of it was studied. The outcome observed by the author were The value of depth of penetration increased by increasing the value of welding current 90, 150 and 210 A. Welding current is factor that will determine the penetration. Penetration also influence by the factors from welding speed and arc voltage. At the graph, the good value of penetration for three various welding speed is 22 V at 210 A.

1.It plotted the highest values of penetration than others. At the welding speed 60 cm/min, the good value for penetration happened is 26 V at 210 A.

2. The hardness at weld bead it is higher value at point 90 A and it slowly dropped to 150 A and at 210 A it small increased than 150 A. The higher value of hardness is 26 V at 90 A at welding speed 60 cm/min.

3. The grain boundaries of microstructure changes from bigger size to smallest size when the variables welding parameters changed. S.W. Campbell et al. [4] performed ANN prediction of weld geometry using gas metal arc welding (GMAW) with alternate shielding gases. The process parameters were shielding gas configuration, voltage, current, travel speed and the responses were penetration, leg length effective throat. The work piece used was steel plates of DH36 grade. The mathematical models were developed by the ANN technique and it gave percentage error less than 10% of all the responses. Addition of Helium gas resulted in an increase in penetration. Increasing the frequency of shielding gas from 2 Hz to 8 Hz resulted in a 0.03 mm increase in penetration, also the increase in travel speed resulted in overall time reduction by 22%. K. Y. Benyounis et al. [5]

Optimized the laser-welded butt joints of medium carbon steel using RSM technique. The objective here was to maximize the depth of penetration and minimize heat input, fusion zone width and HAZ width which were responses. In order to achieve these objectives mathematical models were developed to relate the important weld bead parameters and the laser welding input parameters The input parameters were laser power, welding speed and focused position.

The mathematical models developed and optimized for the weld bead profile are very useful to identify the correct and optimal combination of the laser welding variable, in order to obtain superior weld quality at relatively low cost. To achieve full depth of penetration the optimal working range for the input were LP 1.38 to 1.48 kw, WS 30.48 to 35.55 cm/min, FP -0.43 to 0 mm. and to achieve half depth of penetration LP 1.2 to 1.24 kw, WS 69.77 to 70 cm/min, FP -1.71 to -2.03 mm. The heat input in this case was twice but still less than minimum heat input. The bead width and HAZ width were minimum in half penetration case but are greater than minimum in fill depth of penetration case. Also the welding speed was found to be significant factor here as it was doubled the welding cost will be less resulting in the improving of process productivity. The maximum desirability obtained in the full depth penetration was 0.243 and in half depth penetration it was 0.991.

As Depth of penetration is very important phenomena affected by many parameter like type of material used , welding current, welding angle etc. therefore it becomes necessary to develop a reliable model that predicts the depth of penetration to reduce the cost of welding ,time and money the important process parameters are determined based on literature review carried out on depth of penetration .In this investigation an RSM model is developed which predicts the Depth of penetration. RSM is selected because of its capability to learn and simplify from examples and adjust to changing condition. In addition they can be applied in manufacturing area as they are an effective tool to model non linear system.

2. Response surface Methodology (RSM)

Response surface methodology is one of the optimization techniques in describing the performance of the welding process and finding the optimum setting of parameter. RSM is a mathematical –statistical method that used for modeling and predicting the response of interest affected by input some variable to optimize the response.

RSM also specifies the relationship among one or more measured responses and the essential controllable input factor .when all the independent variable are measured ,controllable and continuous in process ,with negligible error .the response surface model is as shown as follows:

$$y=f(x1, x2.....xn)......................(1)$$

Where "n" is the number of independent variable.

To optimize the response y, it is necessary to find an appropriate approximation for the true functional relationship between independent variable and response surface .usually a second order polynomial eq [2] is used in RSM.

$$y=\beta 0+\sum_{j=1}^{k}\beta j x j+\sum_{j=1}^{k}\beta jj x^2 j+\sum_{i}^{k-1}\sum_{j}^{k}\beta ij x i x j+\varepsilon \quad .....(2)$$

3. Experimental work

In this experiment we have chosen AISI 1020 steel plates of dimension 150*100*6 for square butt welding in given study. AISI 1020 is used by all wide variety of industry sector for application especially in manufacturing sector .AISI 1020 is used by all industry sector for application involving welding plus lightly stressed carburized parts. Typical application are general engineering parts and components, welded structure etc. also carburized components like camshaft, light duty gear ,gudgeon pins, ratches, spindles, worm gear etc. Experimental set up of SMAW machine is as shown in fig 1 which supports both type of polarity i.e (DCEP and DCEN) by which experiment has been accomplanished . The chemical composition of AISI 1020 is as shown table1.

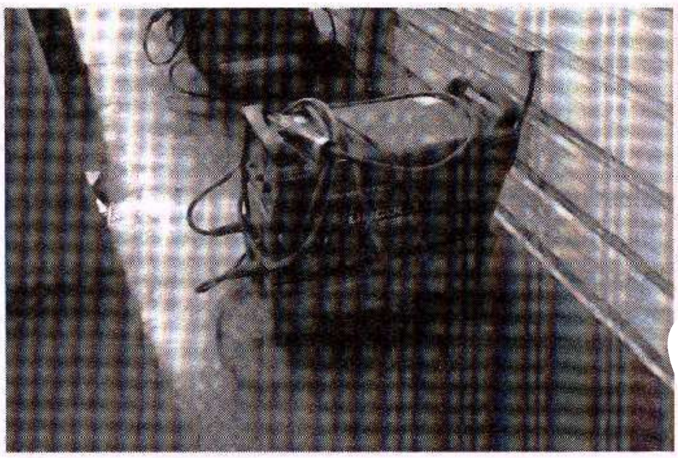

Fig 1. Set up of SMAW welding machine at Marathwada auto cluster (MAC), Waluj

Table 1. Chemical composition of AISI 1020

Carbon	Iron	Mangan-ese	Phosphorus	Sulphur
0.17-0.23%	99.9 -99.53	0.30-0.60	<0.040%	<0.005%

In present study three parameters namely polarity, welding current, welding voltage were considered as input parameter for the measurement of welding strength.

Table 2. Factors and their levels

Sr. no	Level	Polarity	Current	Angle
1	-1	1(DCEP)	90	60
2	0	105	75	
3	+1	2(DCEN)	120	90

4. Result and discussions – The regression table for Depth of penetration is given in table 3. This table shows linear, squared and quadratic effect on depth of penetration.

S=0.0739745 R-sq =98.25% R-sq(adj)=96.69% R-sq(pred)= 92.49%

Linear effect:

The p-value of current, angle, and polarity is less than 0.05. Therefore all these parameter has significant effect on weld strength.

Squared effect: The p- value of the squared effect is more than 0.05.Hence this squared effect has significant effect on welding strength.

Interaction effect: All interaction effects are greater than 0.05. Hence there is no significant effect of these interaction values on welding strength.

Eq (3) represents the relationship between the response and the input parameter

The experimental design and response depth of penetration (DP) is shown in table 4.

Table 4. Experimental design table

Sr. No.	Polarity	Current	Electrode Angle	Depth of penetration (DP)
1	2	105	75	2.08
2	2	90	60	2.03
3	1	90	75	1.20
4	2	105	60	2.15
5	1	90	60	1.20
6	2	120	75	2.20
7	1	120	90	2.0
8	2	90	90	2.10
9	1	105	75	1.35
10	1	105	90	1.45
11	2	120	60	2.18
12	1	120	60	1.65
13	2	120	90	2.30
14	2	90	75	2.03
15	1	120	75	1.75
16	1	90	90	1.30
17	2	105	90	2.30
18	1	105	60	1.30

Table 3. Regression table for depth of penetration

Term	Effect	Coef	SE coef	T-value	P-value	VIF
Constant		1.7306	0.0390	44.39	0.000	
Polarity(A)	0.6856	0.3428	0.0174	19.66	0.000	1.00
Current(B)	0.3700	0.1850	0.0214	8.66	0.000	1.00
Angle(C)	0.1567	0.0783	0.0214	3.67	0.005	1.00
B*B	0.1133	0.0567	0.0370	1.53	0.160	1.00
C*C	0.1233	0.0617	0.0370	1.67	0.130	1.00
A*B	-0.1967	-0.0983	0.0214	-4.60	0.100	1.00
A*C	-0.0433	-0.0217	0.0214	-1.01	0.337	1.00
B*C	0.0750	0.0375	0.0262	1.43	0.185	1.00

The normal probability plot of the residual versus predicted responses for depth of penetration is shown in fig 1 respectively.

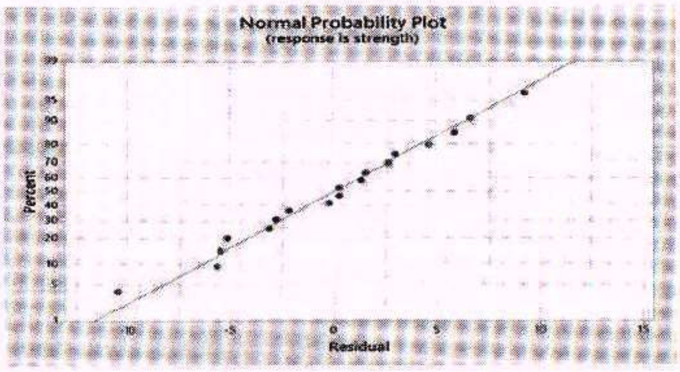

Fig 2. Normal probablity plot for residual for depth of penetration

Fig 2 reveals that the residual generally falls on straight line, implying that error are normally distributed. This implies that the model a proposed is adequate and there is no reason to suspect any violation of the independence or constant variance assumption.

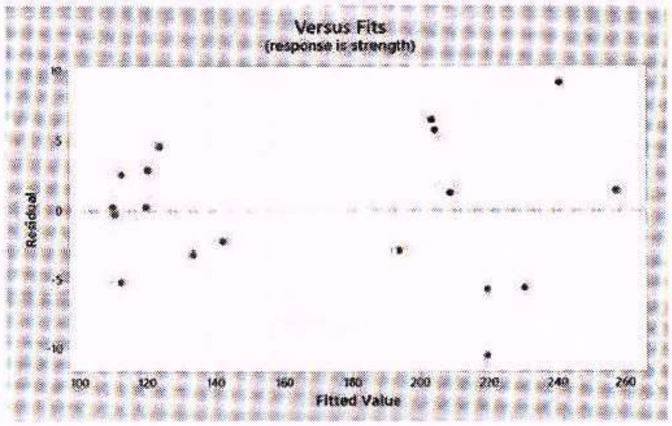

Fig 3. Residual versus fit plot for residual for depth of penetraton

From Fig 3 of residual versus fit plot it is clear that all the points are scattered on the both the sides of zero which means there is constant variance in the model. This implies that the model a proposed is adequate and there is no reason to suspect any violation of the independence.

5. Conclusion –This paper has investigated the effect of stick welding parameters on depth of penetration of AISI 1020 carbon steel and has used response surface methodology for analysis of process parameters. The paper effectively described the linear effects on the RSM based model. The conclusion of this paper present study were drawn as follows:

· The R^2 value is obtained in regression table is 98.23% which itself is evidence that the model is good enough for predicting the depth of penetration. Also, higher the value R^2 the better the model fits the data .

· The linear effect and squared effect which we have obtained were found to be less than 0.05, hence the parameters chosen are significant terms in maximizing the depth of penetration

· From RSM model the predicted and experimental result are quite closed to each other, which indicates that the developed model can be effectively used to predict the depth of penetration.

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