

Effect of Welding Parameters and Electrodes on Bead width using Gas Metal ARC Welding



Sanjeet Kumar, Dipendra Kumar

Abstract: *In this research work, an attempt has been made to formulate and investigate the effect of GMAW conditions on bead width during the cladding of low carbon steel plate using AISI 308H electrodes. The Box-Behnken design has been employed for the development of mathematical relationship. The voltage, current and wire diameter have been considered as cladding conditions. The variation of bead width with voltage and current have been found non linear while, the effect of wire diameter on bead width has been observed linear. On the other hand, the bead width continuously increases with increase in voltage, current and wire diameter.*

Keywords: *Cladding; AISI 308H; low carbon steel; bead width; Box- Behnken design*

I. INTRODUCTION

Some parts of metal require the protection from the corrosion. Compared to low carbon steels, all corrosion resistant alloys are expensive. Also, in various applications, corrosion resistance is needed only on the surface of the material. So cladding on low carbon steel using ASS wire provides the alternative solution at low price. Cladding can save up to 80% of the cost of using solid alloy. The gas metal arc welding (GMAW) expansively used for the fabrication purpose due to higher deposition rate and deeper penetration. The gas metal arc welding is also used for cladding or surfacing. Many researchers studied and investigated the effect of GMAW parameters on cladding parameters. Published work of different researchers in this area is mentioned here.

Murugan and Parmar (1994) employed 5 level full factorial design to investigate the influence of GMAW parameters on the geometry of the weld bead during the cladding of structural steel IS 2062 using 316L stainless steel wire. The voltage has been found most significant parameters that affect the weld width. Murugan and Parmar (1997) used response surface methodology to study the effects of submerged arc welding parameters on AISI316L stainless steel cladding geometry on IS: 2062 structural steel plate. Low dilution has been obtained either both voltage and welding speed are low or high.

Revised Manuscript Received on October 30, 2019.

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Nagesh and Dutta (2002) investigated the influence of SMAW parameters on bead height, bead width, arc travel length, area of penetration and depth of penetration during the cladding of grey cast iron plate using mild steel electrode. The result revealed that bead height and width decreases with increase in arc-travel rate. The bead height decreases with increase in arc-travel rate. Kim et al. (2003) developed mathematical relationship between the welding parameters and bead penetration during the cladding of steel plate with stainless steel. The welding current, arc voltage, welding speed and welding angle have been found significant parameter that affect bead penetration.

Khanna and Murugan (2006) employed response surface methodology to investigate the effect of flux cored arc welding variables on cladding parameters. The cladding has been done on low carbon structural steel plates using duplex stainless steel electrode. The results revealed that reinforcement increases with increase in welding current and nozzle-to-plate distance while decreases with increase in welding speed and welding torch angle. Ganjigatti et al. (2007) used two different approaches for the development of bead geometry prediction models namely globally and cluster-wise regression analyses during the cladding of mild steel plate using steel carbomig S6 wire. The better prediction results have been obtained using cluster wise regression analysis compared to the global approach of regression analysis. Karadeniz et al. (2007) experimentally investigated the effect of welding parameters on bead penetration during the GMAW welding of Erdemir 6842 steel using G3Si1 (SG2) wire electrode. The effect of welding current has been found approximately 2.5 times greater than that of arc voltage and welding speed on penetration. Shahi and Pandey (2008) investigated the effect of gas metal arc welding and universal gas metal arc welding parameters on dilution during the cladding of low carbon structural steel plates using stainless steel wire as electrode. The less dilution has been obtained using UGMAW process as compare to GMAW process. Rao et al. (2009) used Taguchi methodology for the development of weld bead prediction model in terms of GMAW welding parameters during the welding of mild steel plates. The wire feed rate has been found most significant parameter that affect the bead geometry. Kannan and Yoganandh (2010) used five-level central composite rotatable design to develop the empirical relationships between the GMAW parameters and responses during the cladding of carbon structural steel plate using stainless steel solid filler wire. It has been revealed from the results that weld bead width, height of reinforcement, and depth of penetration increases with increase in wire feed rate while weld bead width and height of reinforcement decreases with increase in welding speed.

Wang et al. (2011) investigated the effect of pulsed gas tungsten arc welding parameters on morphology of additive layer of Ti6Al4V. The peak to base current ratio and pulse frequency have been found insignificant effect on refinement of prior beta grain size while wire feed rate has been found significant parameter that affects prior beta grain size. Tham et al. (2012) investigated the effect of welding parameters on bead geometry of 3F fillet joint during the GMAW of carbon steel using ER70S-6 wire electrode. The deviation between predicted weld bead geometry and actual experimental weld bead geometry has been found less than 1.0 mm. Jaime et al. (2013) developed relationship between the GMAW parameters and bead geometry using radial basis function (RBF) based neural network. The welding travel speed, the wire feed speed and the welding voltage have been found influencing parameters that affect the bead geometry. Kumar and Kannan (2013) used GMAW process for the cladding of mild steel plate using super duplex grade stainless steel. The welding speed has been found to influence the sensitivities of the wire feed rate, nozzle to plate distance and welding gun angle. Shreeraj et al. (2014) used central composite rotatable design to develop bead geometry prediction model. Numbers of data set have been generated using develop regression prediction to train artificial neural network using particle swarm optimization technique. It has been revealed that training of artificial neural network using particle swarm optimization technique provide more accurate results instead of training artificial neural network using conventional back propagation algorithm. Turner et al. (2017) investigated the effect of MIG welding parameters on cladding during the cladding of C-CH35ACR low carbon steel base plate using E-7012 solid wire as electrode. It has been revealed from the results that head input decreases with increase in welding speed while bead width increases with increase in arc voltage and welding current. The bead width shows negative effect with increase in amount of CO₂ in the shielding gas. It has been revealed from the review of published literature that numerous researchers have attempt to investigate the effect of welding parameters on bead geometry specially bead penetration. Very less studied have been observed to investigate the effect of different diameter of electrode wire on cladding parameter (bead width). Also, mostly researchers used AISI 304, AISI 304L, AISI 302 etc. electrodes for cladding purpose. These are good cladding electrodes, useful for cladding of low carbon steel parts having low temperature applications. In this research work, An attempt has been done to formulate and investigate the effect of GMAW conditions on bead geometry parameter (bead width) during the cladding of low carbon steel pale with AISI 308H electrodes using Box- Behnken design. The AISI 308 H cladding is useful for high temperature applications such as in the electrical power industry, boilers tubes etc. where better creep resistance is required.

II. MATERIAL FOR WORK PIECE AND ELECTRODE

In the present work, low carbon steel plates having dimension 100mm*50mm*10mm have been selected as a base material for the study of effect of welding condition on cladding. Some application requires high temperature and corrosion resistance parts like tubes of heat recovery steam generators. Generally the tubes of heat recovery steam generators are fabricated using low carbon steel. To reduce the corrosion rates, the tubes are typically protected by coatings. It can be achieve by GMAW cladding using AISI 308H wire. The AISI 308 H cladding is useful for high temperature applications where corrosion resistance with better creep resistance is required. Therefore, in the present research AISI 308 H wires of diameter 1.2 mm and 2 mm have been used for the cladding of low carbon steel plates.

III. EQUIPMENTS FOR CLADDING AND MEASUREMENT OF BEAD WIDTH

The mixture of argon inert gas and oxygen (98% argon and 2% oxygen) at constant flow rate 15 L/min has been used as shielding gas for all experiments. Stand of distance and wire feed rate are kept constant. The cladding has been done GMAW power source with semiautomatic carriage. Then bead width for all beads have been measured with the help of optical profile projector.

IV. SELECTION OF THE GMAW CONDITIONS AND THEIR RANGE

The welding conditions significantly affect the bead geometry parameters. Therefore, control welding parameters is required to achieve quality cladding. It has been revealed from the review of literature that voltage, current, welding speed, wire feed rate are the some commonly used welding parameters. It has also been revealed from the review of literature that diameter of wire has significant effect of bead geometry. On this basis voltage, current and diameter of wire have been taken as GMAW conditions. The range of welding conditions has been chosen according to the published literature and machine specification. For the analysis of present research work, Box- Behnken design has been selected. The table 1 represents the welding conditions and the levels of welding conditions according to Box- Behnken design while table 2 represent the design matrix for experimentation along with the measured values of bead width.

Table 1. GMAW conditions and levels according to Box- Behnken design

GMAW conditions	Units	(-1)	(+1)	(0)
Voltage	Volts	28	36	32
Current	Amp.	100	200	150
Wire diameter	mm	1	3	2



Table 2: Treatments of experiments according to Box-Behnken design and measured values of bead width

S. No.	A: Voltage (Volts)	B: Current (Amp.)	C: Wire diameter (mm)	Bead width (mm)
1	28	100	2	2.74
2	36	100	2	5.26
3	28	200	2	4.00
4	36	200	2	5.87
5	28	150	1	2.75
6	36	150	1	4.63
7	28	150	3	3.48
8	36	150	3	6.10
9	32	100	1	2.91
10	32	200	1	3.91
11	32	100	3	3.99
12	32	200	3	4.89
13	32	150	2	3.90
14	32	150	2	4.10
15	32	150	2	3.70
16	32	150	2	3.85
17	32	150	2	3.92
18	32	150	2	3.60

V. DEVELOPMENT OF EMPIRICAL MODELS FOR BEAD WIDTH

To achieve the objective of present research, Box- Behnken design has been chosen for the development of mathematical relationship using design expert software 8.0.7.1. For the development of mathematical relationship between the GMAW and bead width, the first step is diagnosis of assumptions of analysis of variance. The analysis of variance depends on three assumptions.

- (1) Assumption of “normal distribution of population”
- (2) Assumption of “homogeneity of variance”
- (3) Assumption of “independence”

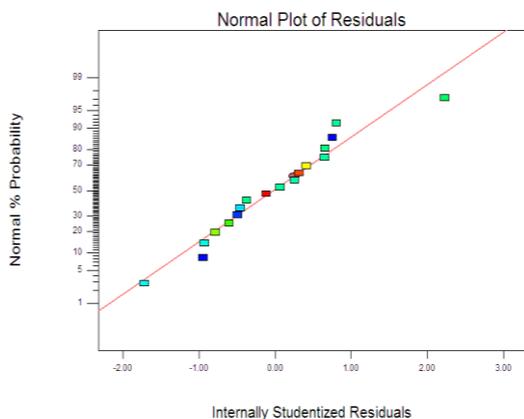


Figure 1 Normal plot of residuals of bead width

To diagnosis the first assumption of ANOVA, the normal probability plot of residuals for bead width is presented in figure 1. If distribution of residuals is normal, the normal percentage probability of residuals (point) will resemble a straight line on plot. The figures display that the

major normal percentage probability of residuals (point) for bead width generally fall on a straight line implying that the residuals for bead width are distributed normally.

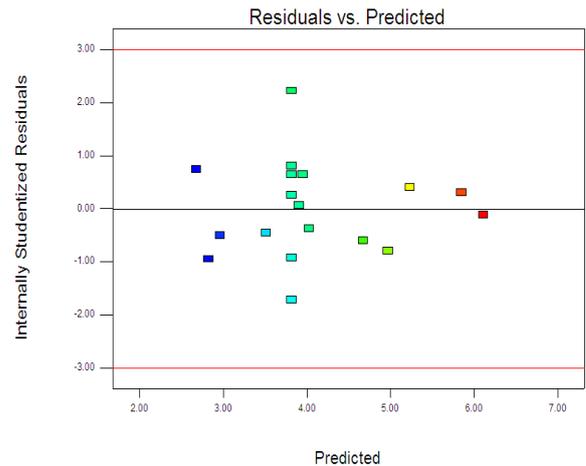


Figure 2. Residuals v/s predicted plot for bead width

To diagnosis the second assumption of ANOVA, the residuals versus the predicted values for bead width is presented in figure 2. The residual versus the predicted plot shows whether the residuals have constant variance or not. If the residuals follow assumption of constant variance, the plot should have no obvious pattern. From the figure, it has been revealed that plot have no obvious pattern. This implies that residuals for bead width follow assumption of constant variance.

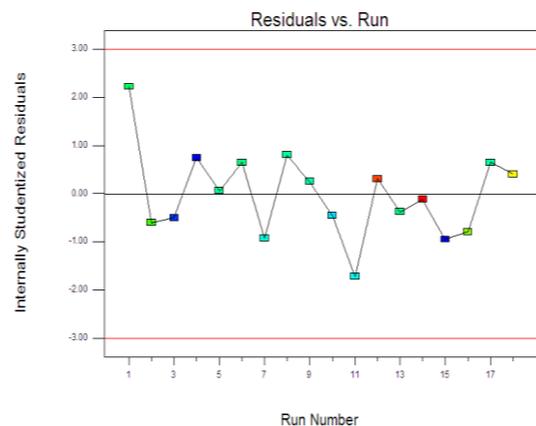


Figure 3 Residuals v/s run order plot for bead width

To diagnosis the third assumption of ANOVA, the residuals versus run order for bead width is presented in figure 3. The residuals versus run order plot shows whether the residuals for each treatment (run order) follow same pattern or not. If the residuals follow assumption of independence, the plot should have no definite pattern. From the figure, it has been revealed that figures have unusual pattern. This implies that residuals for bead width follow assumption of independence.

A. ANOVA Table Analysis

In the present work, the analysis of variance is conducted at a significance level of $\alpha = 0.05$ for all the bead geometry conditions. The table 3 shows the reduce ANOVA table after the backward elimination for the bead width.

Table 3 Reduce ANOVA table for bead width

Source	Sum of square	D O F	Mean square	F-Value	p-value Prob > F
Model	15.27	7	2.182	117.2	0.0001
A- Voltage	9.89	1	9.89	531.4	0.0001
B- Current	1.78	1	1.777	95.5	0.0001
C-Wire diameter	2.26	1	2.258	121.3	0.0001
AB	0.11	1	0.107	5.8	0.0373
AC	0.14	1	0.141	7.56	0.0205
A^2	0.93	1	0.934	50.2	0.0001
B^2	0.10	1	0.097	5.19	0.0459
Residual	0.19	0	0.019		
Lack of Fit	0.03	5	0.006	0.20	0.9478
Pure Error	0.15	5	0.031		
Cor Total	15.46	7			
Std. Dev.	0.14		R-Squared		0.988
Mean	4.09		Adj R-Squared		0.98
C.V. %	3.34		Pred R-Squared		0.974
PRESS	0.41		Adeq Precision		37.707

As shown in table 3, the voltage, current, wire diameter, interaction of voltage & current, voltage & wire diameter and second order term of voltage and current have been found significant bead width model terms. The R², adjusted R² and adequate precision value have been found as 0.988, 0.9795 and 37.7 respectively.

B. Bead Width Prediction Model

The mathematical model for bead width in terms of actual values of GMAW parameters are shown by the equation 1.

$$\begin{aligned}
 \text{Bead width} &= 22.33 - 1.536 * \text{Voltage} + 0.0178 * \text{Current} - 0.969 \\
 &* \text{Wire diameter} - 0.00081 * \text{Voltage} * \text{Current} \\
 &+ 0.0469 * \text{Voltage} * \text{Wire diameter} + 0.0288 \\
 &* \text{Voltage}^2 + 0.00006 \\
 &* \text{Current}^2 \tag{1}
 \end{aligned}$$

A graph between the experimental and predicted values of bead width is shown in figure 4.

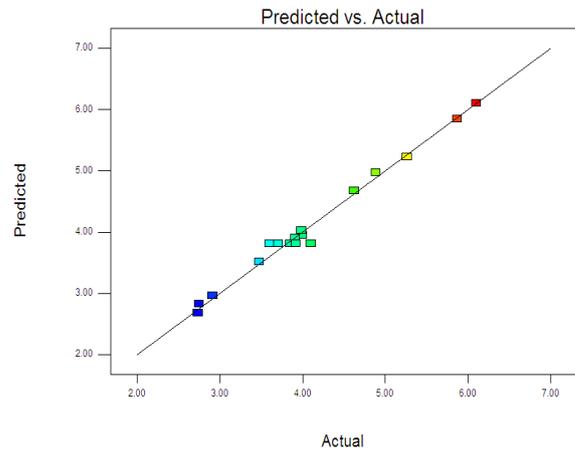


Figure 4. predicted v/s experimental plot for bead width

These plots help in detection of new values, or group of values. The data points should split evenly by the 45 degree line for the good prediction. The figures reveal that all the data points split evenly by the 45 degree line.

VI. VI. EFFECT OF GMAW CONDITIONS ON BEAD WIDTH

The figure 5 shows the main effect plot between the voltage and bead width. The plots have been plotted at the mean values of current (150 A) and wire diameter (2 mm). From the plot it has been revealed that the variation of bead width with respect to voltage is non linear (curvature). It is clear from the plots that bead height continuously increases with increase in voltage from 28 V to 36 V. It is due to the fact that the arc length increases with increase in voltage.

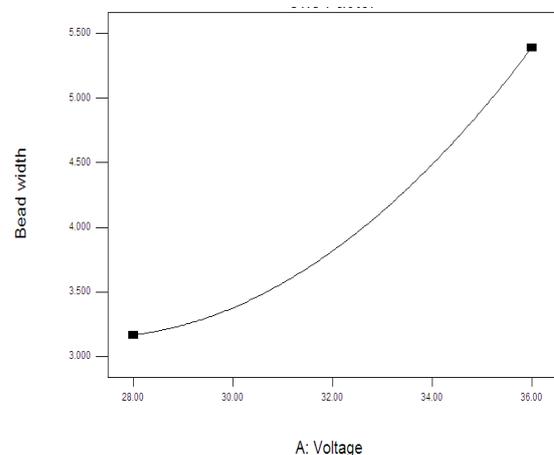


Figure 5 Voltage v/s bead width plot

The cone of arc of high length spread at its base, resulting in more melting of the base plate surface because of high heat input per unit length. This increases the bead width.

The figure 6 represents the effect of current on bead width at the mean value of voltage (32 V) and wire diameter (2mm).

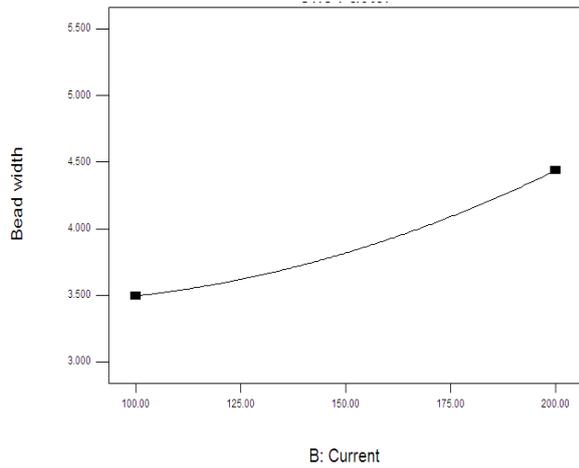


Figure 6. Current v/s bead width plot

It is visible from the figure that variation of bead width with current follow quadratic (curvature) path. It is also clear from the figure that bead width increases with increase in current. The power per unit length of weld bead increases with increase in current, which melt the larger volume of base metal, also, the velocity and acceleration of the molten droplets increases with increase in current. This increases the deposition rate; hence increase in bead width.

The effect of wire diameter on bead width is shown in figure 7 at the mean value of current (150 A) and voltage (32 V). The effect of wire diameter on bead width has been observed linear. From the figure it has been revealed that bead width increases with increase in wire diameter. It is due to the fact that larger sizes of droplets of welding wire formed with larger wire diameter. This results in wider the bead.

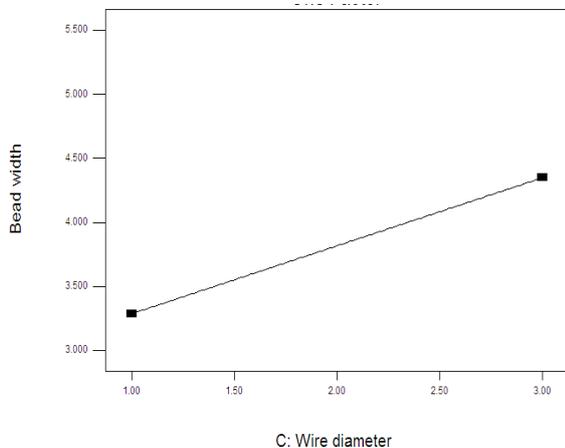


Figure 7 Wire diameter v/s bead width plot

The figure 8 shows the 3D plot for bead width in terms of voltage and current at the mean value of wire diameter (2mm). The curvature of the plot along voltage shows that the variation of bead width is non linear with respect to voltage while the variation of bead width is linear with respect to current. The bead width increases with increase in current and voltage. The maximum bead width is obtained at 200 A current and 36 V voltage while minimum bead width is obtained at 28 V voltage and 100 A current.

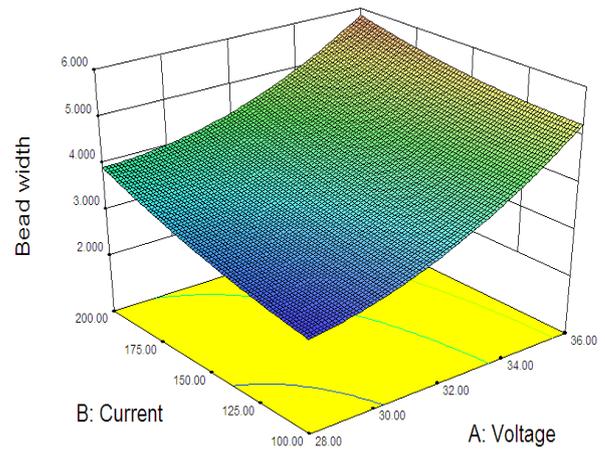


Figure 8: 3D plot for bead width in terms of voltage & current

The figure 9 shows the 3D plot for bead width in terms of voltage and wire diameter at the mean value of current (150 A). The figure shows that the variation of bead width is linear with respect to wire diameter. The bead width increases with increase in wire diameter and voltage. The maximum bead width is obtained with 3 mm wire diameter at 36 V voltage while minimum bead width is obtained at 28 V voltage with 1 mm wire diameter.

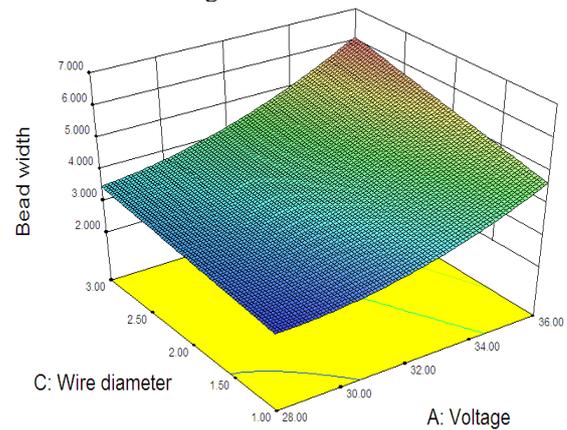


Figure 9: 3D plot for bead width in terms of voltage & wire diameter

VII. CONCLUSION AND FUTURE SCOPE

In this research work, an attempt has been made to formulate and investigate the effect of GMAW conditions on bead width during the cladding of low carbon steel plate using AISI 308H electrodes. The Box- Behnken design has been employed for the experiments design and development of mathematical relationship. The following conclusions have been derived from the present research:

- The variation of bead width with voltage and current have been found non linear while, the effect of wire diameter on bead width has been observed linear.
- The bead width continuously increases with increase in voltage and current.
- The bead width increases with increase in wire diameter.

- From the analysis of ANOVA for bead width, voltage has been observed most significant parameter followed by wire diameter and current.
- The R-Squared and Adj R-Squared values for bead width have been found as 0.988 and 0.9795 respectively, which is very close to one, that's show the good prediction ability of the develop model.

In the present research, voltage, current and wire diameter have been used as GMAW conditions. The study of wire feed rate, welding speed, inert gas flow rate, types of electrode wires etc. also useful during the cladding. So, study of bead width by considering these conditions will be quite useful for future studies.

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