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Predicting the Weld Bead Geometry of Tig Welding and Generating a Mathematical Model by Box Benkahn

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Abstract - *The prediction of the optimal bead geometry is an important aspect in welding process. Therefore, the mathematical models that predict and control the bead geometry require to be developed. This paper focuses on investigation of the development of the simple and accuracy interaction model for prediction of bead geometry in TUNGSTEN INERT GAS (TIG) welding process. The independently controllable parameters affecting weld pool geometry and the quality of the weld pool V, I, and F were selected as input control variables. The experimental designed and constructed to control the linear movement of the torch along the weld pad center line. Weld pools were laid on the joint to join thin stainless steel plate with the experimental setup. 316 stainless steel plates of 3mm thicknesses are going to be used as a work piece material. The specimens joined using a single pass welding. The quality parameters are measured. The suitable mathematical relationship is going to be generated. This developed systematic approach can also be adopted for other type of arc welding processes.*

Keywords: *GTAW, Bead geometry, Mathematical model.*

1. INTRODUCTION

TIG welding is an arc-welding process that produces coalescence of metals by heating them with an arc between a non-consumable tungsten electrode and the base metal. Many delicate components in aircraft and nuclear reactors are TIG welded due to its reliability. Basically, TIG weld quality is strongly characterized by the weld pool geometry as shown in Figure 1. This is because the weld pool geometry plays an important role in determining the mechanical properties of the weld.

TIG welding is a highly non-linear, strongly coupled, multivariable process. The weld pool geometry and, hence, the quality of TIG welded joints are greatly dependent on the selection of input control variables such as welding speed (V), welding current (I), shielding gas flow rate (F). Therefore, in the TIG welding, engineers often face with the problem of selecting appropriate and optimum combinations of input control variables for the required weld pool quality.

In this work, nonlinear and multi-objective mathematical models are developed for the selection of the optimum processes parameters. First, the upper and lower limits of the input control variables are obtained and the effect of the input control variables on the weld pool quality parameters is determined. Then, the mathematical relationships between the input control variables and weld pool quality parameters are obtained. These relationships are considered as objective functions in the mathematical models.

To the best of our knowledge the optimization problem of the TIG welding using nonlinear and multi-objective mathematical models has not been investigated previously and applied on real life case study like in this work.

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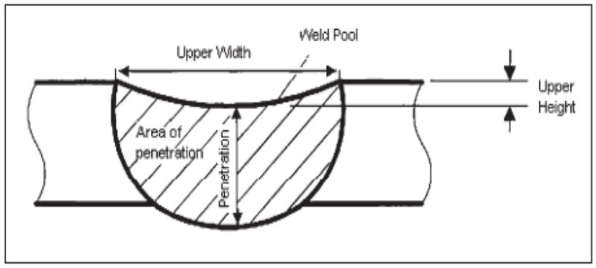

Fig.1 Weld bead dimensions

2. A Systematic Approach

Development of a systematic approach is required to obtain optimum combinations of input control variables for the required weld pool quality system. This approach includes the following steps.

i. Identify the process control variables and their Upper and lower limits
ii. Identify the quality parameters,
iii. Construct mathematical models,
iv. Develop a design matrix,
v. Conduct experiments,
vi. Obtain mathematical relationships,
vii. Apply the constructed models.

2.1 Input Process Control Variables

The independently controllable parameters affecting weld pool geometry and the quality of the weld pool V, I, and F were selected as input control variables.

2.2 Weld Pool Quality Parameters

It is possible to present the quality of welding geometry with the P, AP, UW and UH. These parameters are important weld quality parameters and all of them are considered in this study.

2.3 Development of the Design Matrix

The design matrix should be depending on the upper and the lower limits of the predetermined input control variables. The selected design matrix is a three-level, three-factor, central composite rotatable response surface design consisting of 13 sets of design matrix. It comprises response surface design (RSD).

The upper limit of a variable was coded as +1 and the lower limit as –1. The coded values for intermediate values were calculated from the rotatable central composite design of Design Expert 8.0 as given in table1

Welding parameters	Min value	Intermediate value	Max value
Travel speed (mm/s)	1.85	2.28	2.7
Current (A)	75	87.5	100
Gas flow rate (lpm)	10	11	12

Table 1

For each of determined combination of the input control variables (V, I, and F) perform the TIG welding and determine the value of the quality parameters using conducting experiments. The determined combination is shown in table 2.

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S.no	Welding speed (mm/s)	Welding current (A)	Gas flow rate(lpm)
1	1.85	87.5	12
2	2.28	100	10
3	2.70	75	11
4	2.28	75	12
5	2.28	75	10
6	2.70	100	11
7	1.85	87.5	10
8	1.85	75	10
9	2.7	87.5	12
10	2.28	100	12
11	2.7	87.5	10
12	2.28	87.5	11
13	1.85	100	11

Table 2

3. Conducting Experiments

The experimental set up was designed and constructed to control the linear movement of the torch along the weld pad centre line. The experiments were conducted according to the design matrix at random order to avoid systematic errors infiltrating the system.

Weld pools were laid on the joint to join thin stainless steel plate with the experimental setup. 316 stainless steel plates of 3 mm thicknesses were used as a workpiece material. The specimens were joined using a single pass welding tungsten electrode with 3 mm diameter and argon as shielding gas. The welded joints were sectioned to produce specimens for examining the quality parameters (UW, UH, P) of weld pool shape in the welded specimens.

4. Results and Discussions

4.1 Direct Effect of Process Parameters

The effect of process parameters on bead geometry were discussed below.

4.1.1 Direct Effect of Welding Current on Bead Parameters

From the final mathematical models, the direct effects of process parameters on bead geometry were determined and presented. It is clear from the fig 2 that penetration increases with the increase in welding current (I), keeping the other variables constant. This is due to the fact that the increase in welding current resulting in enhanced heat input, causing large volume of the base metal to melt and hence deeper penetration. Bead width increases by increasing in welding current (I). . It is clear from the graph that upper width increases with the increase in welding current (I), keeping the other variables constant.

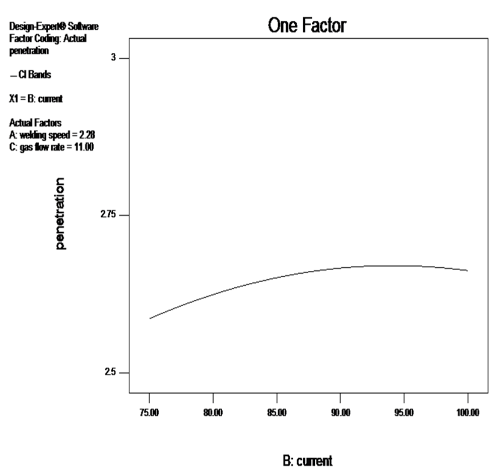

Fig 2. Direct effect of current on penetration

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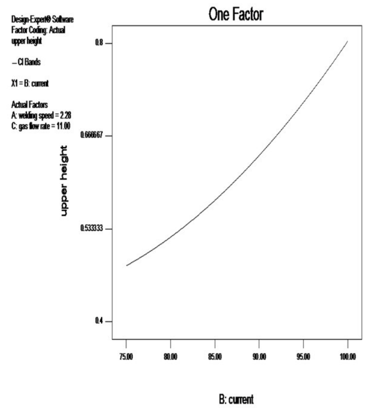

Fig 3 Direct effect of current on upper height

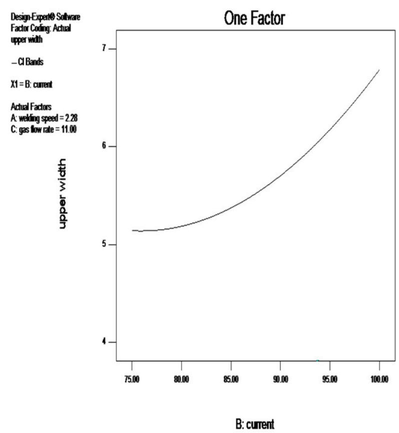

Fig 4 Direct effect of current on upper width

4.1.2 Direct Effect of Welding Speed on Bead Parameters

From the fig 5, it is evident that penetration decreases with increase in welding speed. Also from fig 6, it is evident that upper height increases initially, this is due to the fact more melting of base metal. From the fig 7, it is evident that upper width increases initially and decreases. This is due to the fact more melting of base metal initially when speed is less.

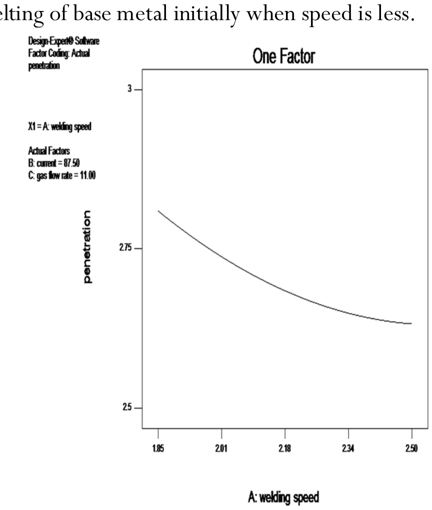

Fig 5. Direct effect of welding speed on penetration

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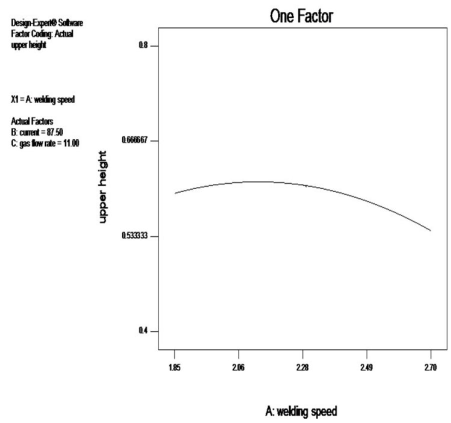

Fig 6. Direct effect of welding speed on upper height.

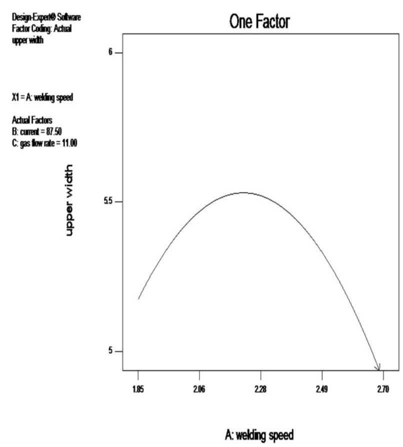

Fig 7 Direct effect of welding speed on upper width.

4.1.3 Direct Effect of Shielding Gas Flow Rate on Bead Parameters

From the fig 8, it is evident that penetration, upper width, upper height increases with increase in shielding gas flow rate. From the fig 9, it is clear that upper height decreases with increase in shielding gas flow rate. From the fig 10, it is clear that upper width decreases with increase in shielding gas flow rate.

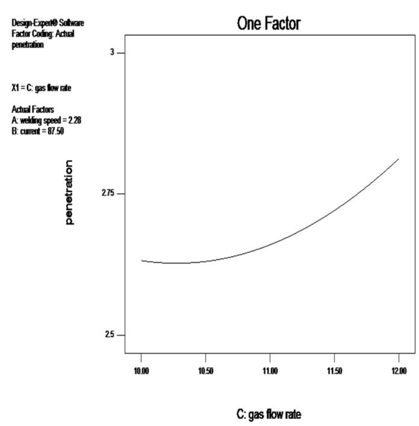

Fig 8. Direct effect of gas flow rate on penetration

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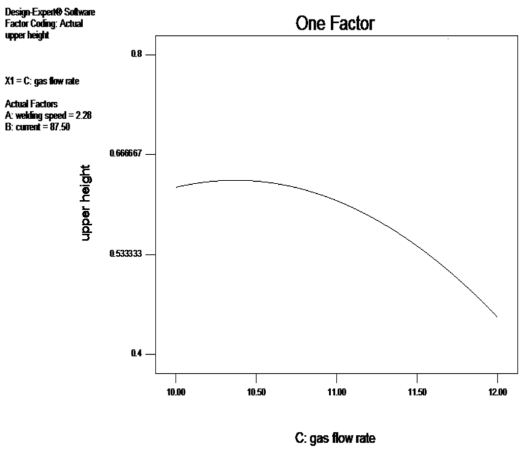

Fig 9 Direct effect of gas flow rate on upper height.

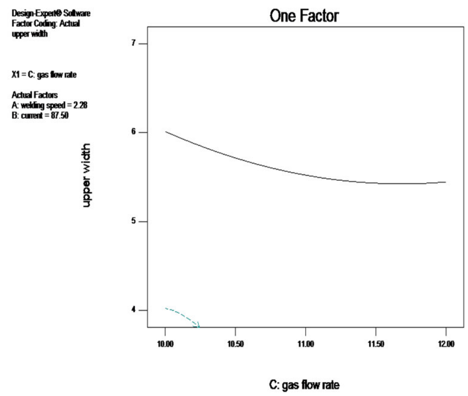

Fig 10 Direct effect of gas flow rate on upper width.

4.2 Interaction Effects of Process Variables on Bead Dimensions

The combinational effect of the above discussed three process parameters on bead geometry also studied.

4.2.1 Interaction Effect of Welding Current and Welding Speed on Upper Height

The fig 11 shows the interaction effect of welding current and welding speed on upper height. That is the graph gives the values of upper height for the combination of current and welding speed.

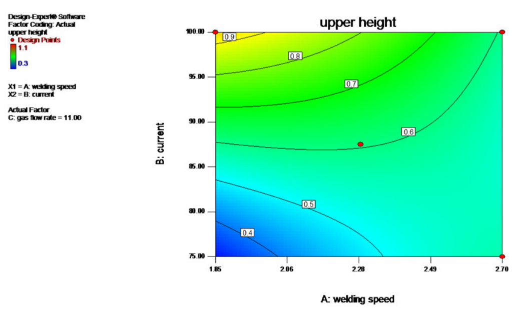

Fig 11. Interaction effect of welding speed and current on upper height.

4.2.2 Interaction Effect of Welding Current and Welding Speed on Upper Width

The fig 12 shows the interaction effect of welding current and welding speed on upper width. That is the graph gives the values of upper width for the combination of current and welding speed.

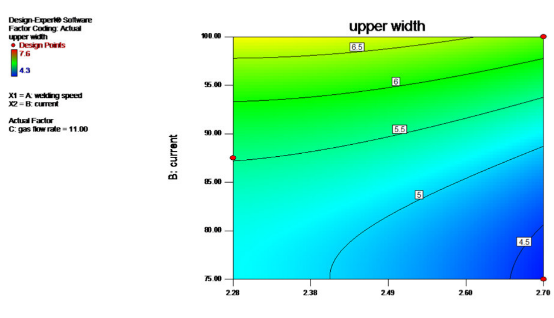

Fig 12 Interaction effect of welding speed and current on upper width.

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4.2.3 Interaction Effect of Welding Current and Welding Speed on Penetration

The fig 13 shows the interaction effect of welding current and welding speed on penetration. That is the graph gives the values of penetration for the combination of current and welding speed.

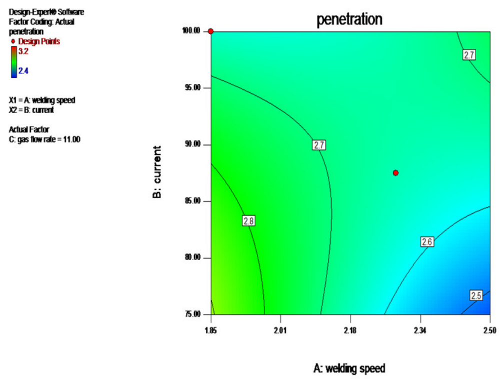

Fig 13 Interaction effect of welding speed and current on penetration.

7.2.4 Interaction Effect of Welding Current and Gas Flow Rate on Upper Height

The fig 14 shows the interaction effect of welding current and gas flow rate on upper height. That is the graph gives the values of upper height for the combination of current and gas flow rate.

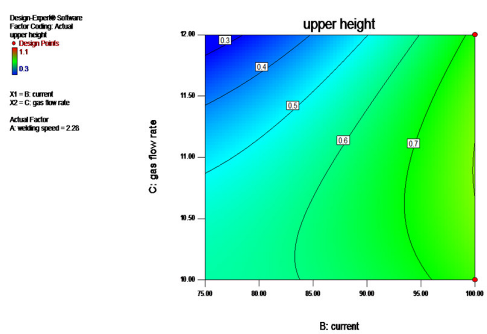

Fig 14Interaction effect of gas flow rate and current on upper height.

7.2.5 Interaction Effect of Welding Current and Gas Flow Rate on Upper Width

The fig 15 shows the interaction effect of welding current and gas flow rate on upper width. That is the graph gives the values of upper width for the combination of current and gas flow rate.

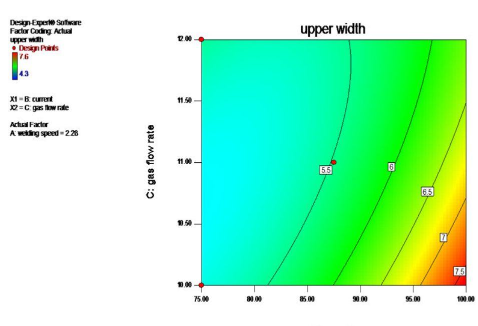

Fig 15 Interaction effect of gas flow rate and current on upper width

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7.2.6 Interaction Effect of Welding Current and Gas Flow Rate on Penetration

The fig 16 shows the interaction effect of welding current and gas flow rate on penetration. That is the graph gives the values of penetration for the combination of current and gas flow rate.

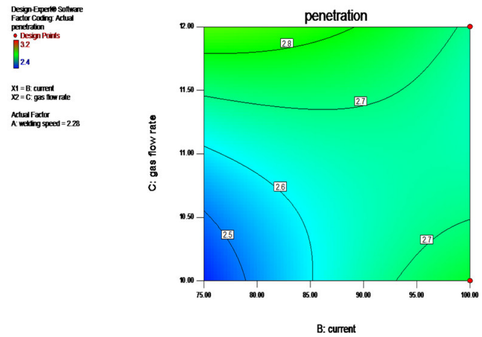

Fig 16 Interaction effect of gas flow rate and current on penetration.

7.2.7 Interaction Effect of Welding Speed and Gas Flow Rate on Upper Height

The fig 17 shows the interaction effect of welding speed and gas flow rate on upper height. That is the graph gives the values of upper height for the combination of speed and gas flow rate.

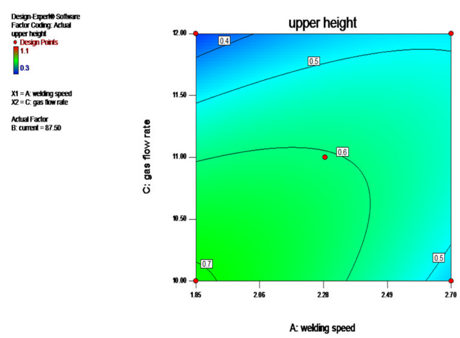

Fig 17 Interaction effect of gas flow rate and speed on upper height.

7.2.8 Interaction Effect of Welding Speed and Gas Flow Rate on Upper Width

The fig 18shows the interaction effect of welding speed and gas flow rate on upper width. That is the graph gives the values of upper width for the combination of speed and gas flow rate.

7.2.9 Interaction Effect of Welding Speed and Gas Flow Rate on Penetration

The fig 19 shows the interaction effect of welding speed and gas flow rate on penetration. That is the graph gives the values of penetration for the combination of speed and gas flow rate.

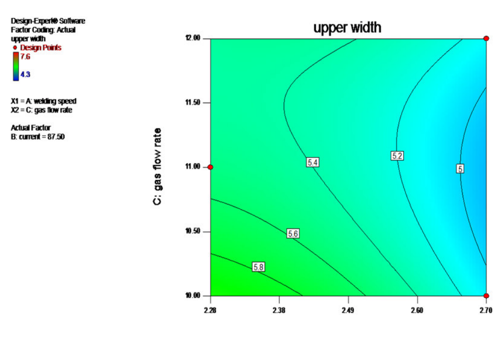

Fig 18 Interaction effect of gas flow rate and speed on upper width.

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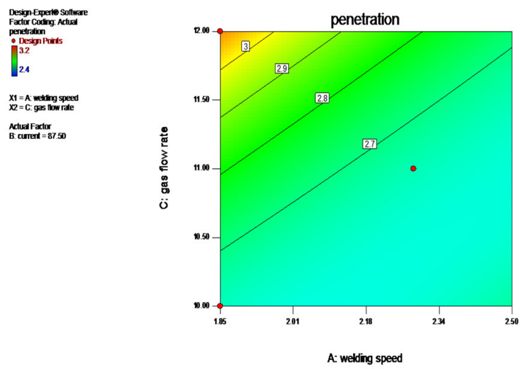

Fig 19 Interaction effect of gas flow rate and speed on penetration.

4.1.4 Mathematical Model

The relationship between the process parameters and bead geometry is given below.

Upper width = +5.52 - 0.14* A + 0.82* B - 0.28 * C + 0.15 * A* B + 0.31 * A * C - 0.41 * B * C - 0.48 * A^2 + 0.44 * B^2 + 0.21 * C^2

Upper height= +0.61 - 0.026 * A + 0.16 * B - 0.087* C - 0.15 * A * B + 0.097 * A * C + 0.073 * B * C - 0.038 * A^2 + 0.037 * B^2 - 0.069 * C^2

Penetration= +2.66 - 0.086 * A + 0.038 * B + 0.090 * C + 0.17* A* B - 0.13 * A * C-0.13 * B * C + 0.062 * A^2 - 0.036* B^2 + 0.062* C^2

5. Conclusion

A systematic approach has been developed and employed in this study for the optimization problem of the TIG welding process parameters. The mathematical relationships between input control variables and weld pool quality parameters are obtained using the results of experiments. Mathematical models are constructed and solved under the predetermined limits of the input control variables using the obtained mathematical relationships as objective functions. This developed systematic approach can also be adopted for other type of arc welding processes.

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