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Optimization of TIG Welding Process Parameters using Fractional Factorial Design of Experiment

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ABSTRACT

TIG welding is preliminary welding process in heavy fabrication industry. There are different Optimization Techniques, however experimental approach is fundamental approach, since it provides mathematical model and hence opportunity for optimization using mathematical model. This paper attempts to optimize the TIG welding process variables, using Fractional Factorial Design (FFD). It is very efficient and effective Optimization Technique, especially when the experimental runs are time consuming and costlier from financial viewpoint (Process Stability is important). It is found that the mathematical model is suitable in predicting the response. Optimum conditions of process variables are provided in the section "Optimization of Response".

***Keywords*—GTAW Welding, Fractional Factorial Design, Process Optimization, TIG Factor Setting, Effective Welding Condition.**

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I. INTRODUCTION

TIG Welding is process in which an arc is maintained between non-consumable tungsten electrode and the work-piece, within inert gas environment which becomes a heat source. Filler rod is consumable and is fed from outside, its material composition is same as that of parent material [1]. Operational principle of TIG welding process is shown in Fig.-1.

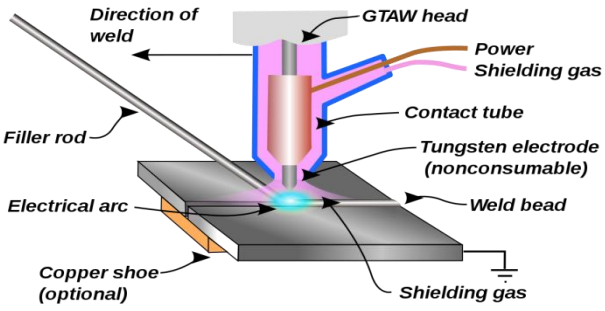

Fig.-1: TIG-Tungsten Inert Gas Welding Process Scheme [2]

TIG Welding is effectively used for joining ferrous and non-ferrous material with similar and dissimilar combination. Generally Ar, He and Ar + He mixtures are used as shielding gas for ferrous material welding whereas nitrogen is used as shielding gas for welding copper [3].TIG is costlier method and hence should be effectively and efficiently used by running it at optimum condition

I. FRACTIONAL FACTORIAL DESIGN

Fractional Factorial Designs (FFD) are carefully chosen fraction of Full Factorial Design, in order to exploit the "sparsity of effects principle" to expose maximum information of problem under consideration. Fractional Factorial Design is chosen based on the resolution of design. Resolution is the size of word length used in generator. As a thumb rule, low resolution designs are used for estimating main effects, whereas high resolution designs are used for estimating main and interaction effects. Fractional Factorial Design is used in the field of science and technology for the purpose: 1) Screening Important Factors, and 2)

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Optimization. Fractional factorial contains less number of runs as the fraction of Full Factorial Design. It is generally expressed as L^{f-p}, where L is the level of factors to be studied, f is number of factors, and p is the size of fraction of full factorial design [4].

II. Factor Levels and Data Collection

Factor ranges decided on the basis of practical experience so as to obtain feasible search space. Coded values transformed into uncoded values using following transformation [5]:

$$Variable = Mean + Coded\ value * (Range/2)$$

Thus following relations obtained for converting coded values of design variables into uncoded values (actual values).

$$Root\ Gap = 2.4 + 0.8 * A$$

$$Filler\ Rod\ Dia. = 2.0 + 0.4 * B$$

$$Electrode\ Dia. = 2.4 + 0.8 * C$$

$$Current = 115 + 25 * D$$

$$Thickness = 7.5 + 2.5 * E$$

$$Purging\ Gas\ Flow\ Rate = 8 + 2 * F$$

$$Gas\ Flow\ Rate = 10 + 2 * G$$

Table-1 shows the data collection format, in which, there are seven input factors and one response variable. Data collected for response variable shown in last column.

Table-1: Fractional Factorial Design-7 Factors and 2 Levels (Resolution-III)

Sr. No.	Root Gap	Filler Rod Diameter	Electrode Diameter	Current	Thick-ness	Purging Gas Flow Rate	Gas Flow Rate	Tensile Strength(UT
	mm	mm	mm	ampere	mm	l/min	l/min	MPa
	A	B	C	D	E	F	G	y
1	1.6	2.4	1.6	90	10	6	8	343.28
2	3.2	1.6	3.2	140	10	6	8	507.58
3	3.2	2.4	3.2	90	10	10	12	447.76
4	3.2	1.6	1.6	90	5	10	8	555.00
5	1.6	1.6	1.6	140	10	10	12	309.05
6	3.2	2.4	1.6	140	5	6	12	415.84
7	1.6	1.6	3.2	90	5	6	12	514.85
8	1.6	2.4	3.2	140	5	10	8	225.00

III. Overall Methodology

Overall methodology followed during project is shown in Fig-2 below.

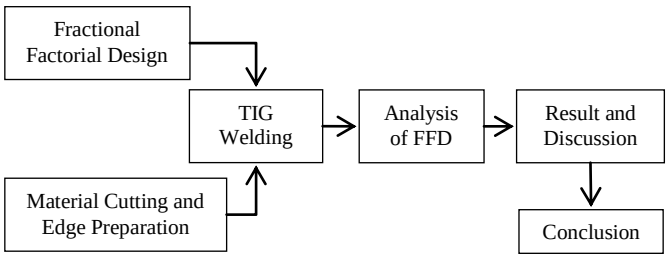

Fig-2: Overall Methodology of Experimentation

Material cut into size of 100 mm X 100 mm in different thicknesses such as 5 mm, 8 mm and 10 mm, as shown Fig-3.

Fig-3: 100 mm X 100 mm plates (Thickness=5 mm and 8 mm)

These cut pieces then chamfered on one side for creating root in the weld. TIG welding operation carried with qualified welder. For easy identification and avoid possible mis-happening during testing, all pieces were identified as FFD-1 upto FFD-8 on both plates before welding. FFD is analyzed with the help of Minitab-17. Statistical and analytical approaches used in analyzing the data collected. Optimum condition for TIG welding is put in the Optimization Section.

Generally DOE tools are applied, when process is stable. Hence control chart (Fig-3) is plotted.

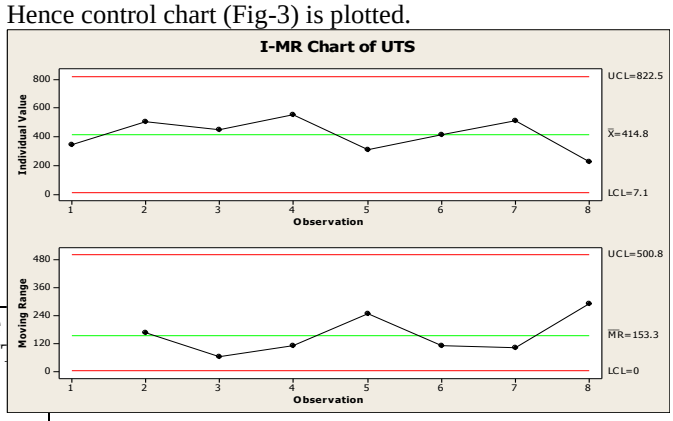

Fig-4: Control Chart to Check Welding Process Stability

The above chart (Fig-4) shows that all the data-points for Individual and Moving Range chart, lies within UCL and LCL. Additionally, no special pattern is observed, and hence the process is stable. Therefore fractional factorial design can be directly used for optimizing the response variable.

IV. Analysis of Data

From the Pareto chart of the effects (Fig-5), we see that effects A, B, D and F are significant, whereas effects E, C and G are insignificant.

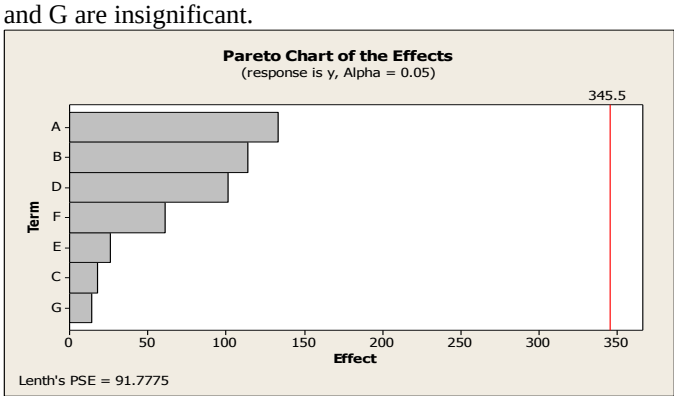

Fig-5: Pareto Charts of the Effects

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This is also clear from the main effects plot (Fig-6)

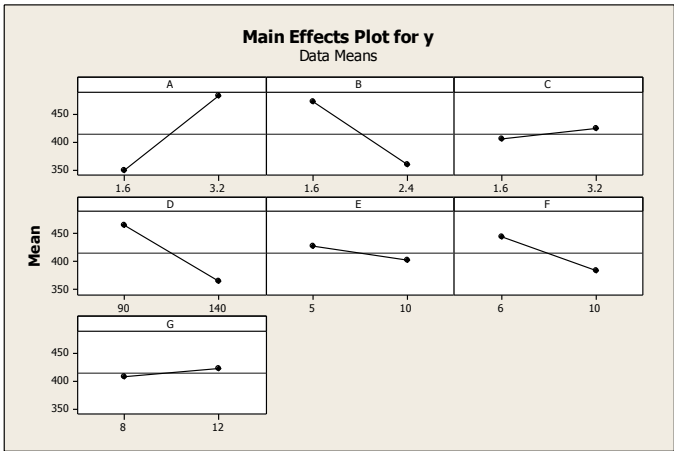

Fig-6: Main Effects Plot

A. *Analysis of Regression Model*

This regression model has MSE=0, Mean Sum of Squares is zero, the exceptional case.

$$y = 829.231 + 83.4375A - 142.063B + 11.2531C$$
$$-2.017D - 5.151E - 15.2963F + 3.54G$$

However, after removing the insignificant factors, above model reduces to.

$$y = 853.006 + 83.4375A - 142.063B - 2.017D - 15.2963F$$

From Fig-7, it is seen that, interaction do not occur between factors except for AF which is negligible.

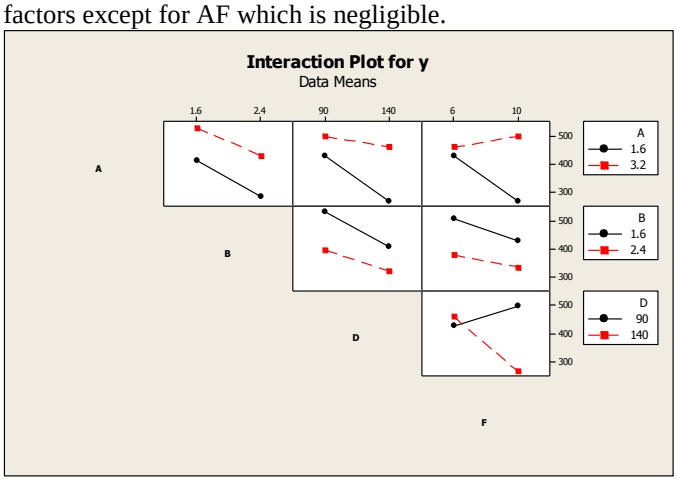

Fig-7: Interaction Plot of Factors

B. *Analysis of Regression Model*

Normal Probability Plot (Fig-8) shows that the residuals are distributed near to the straight line, indicates that residuals are normally distributed.

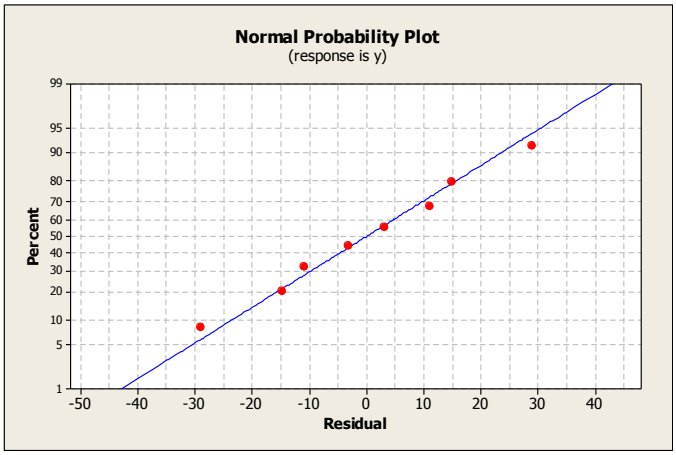

Fig-8: Normal Probability Plot of Residuals

Looking at Fig-9, it is seen that residuals are randomly distributed and no particular pattern is indicated.

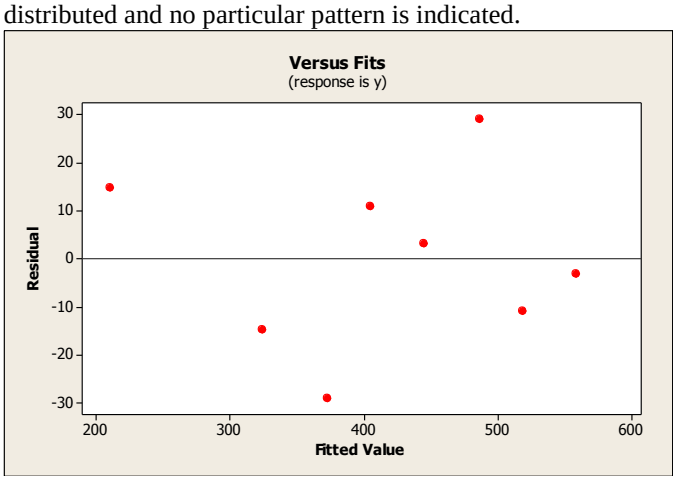

Fig-9: Residuals Vs. Fitted value

V. Optimization of Response Variable

A. *Analysis of Surface Plots*

For four significant variables, six surface plots are produced. All surface plots are planar. Hence, for maximization of response variable, the top most corner gives the setting of factors.

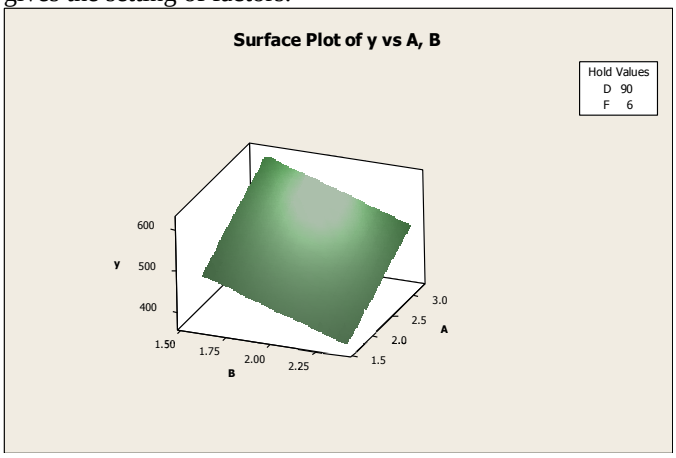

Fig-10: Surface Plot of ‘y’ Vs. A and B

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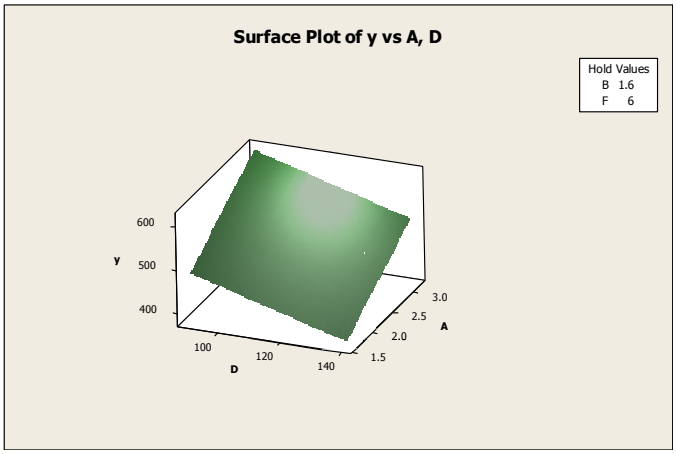

Fig-11: Surface Plot of 'y' Vs. A and D

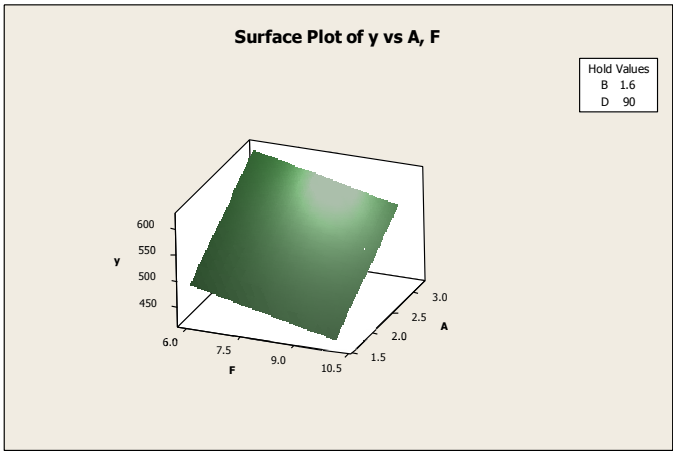

Fig-12: Surface Plot of 'y' Vs. A and D

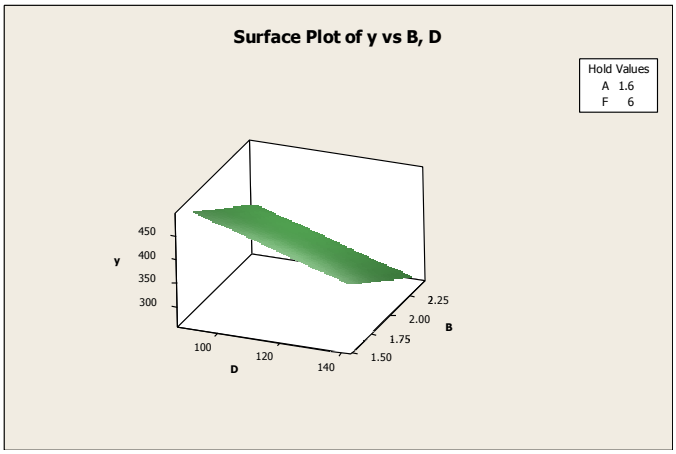

Fig-13: Surface Plot of 'y' Vs. B and D

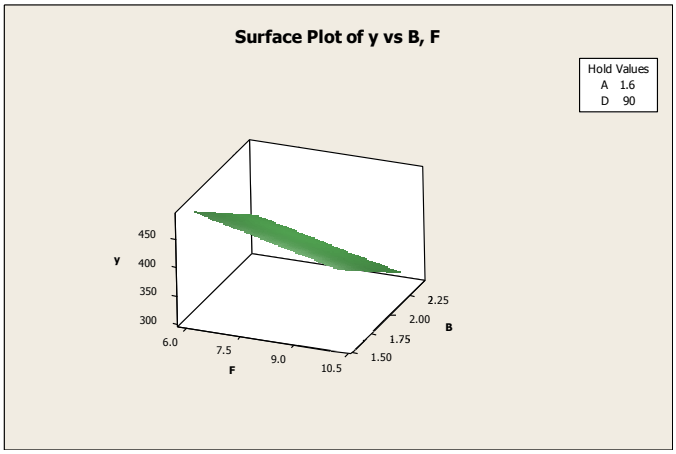

Fig-14: Surface Plot of 'y' Vs. B and D

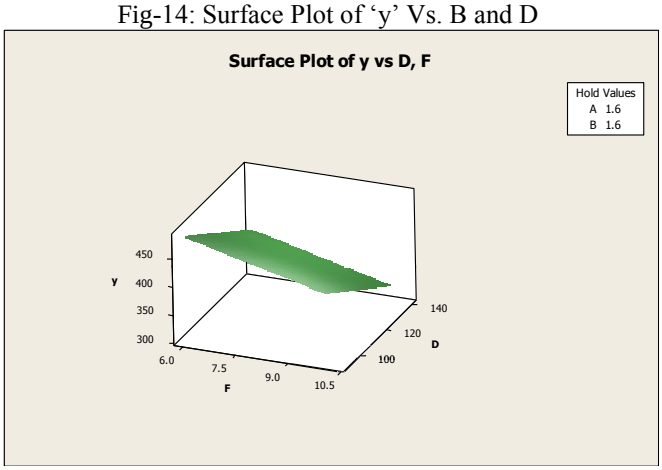

Fig-15: Surface Plot of 'y' Vs. B and D

VI. Optimization of Response

For maximization of response variable, the default value of desirability factor d=1.0 is considered.

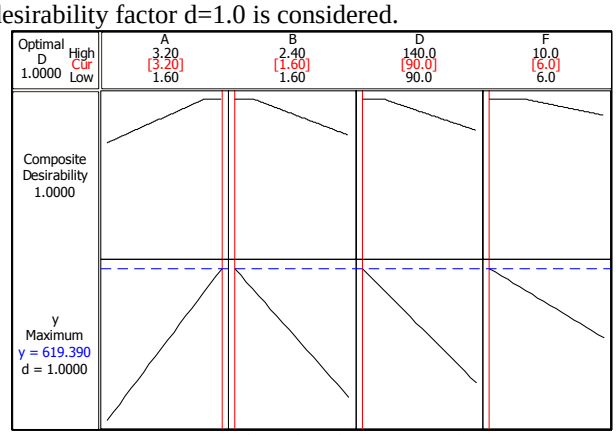

Fig-16: Surface Plot of 'y' Vs. B and D

The maximum value of factors is tabulated in Table-2.

Sr. No.	Variable	Unit	Opt. Value
1	Tensile Strength (Max.)	MPa	619.39
2	Root Gap	mm	3.2
3	Filler Rod Diameter	mm	1.6
4	Current	Ampere	90
5	Purging Gas Flow Rate	l/min	6

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VII. Result Validation

The result is validated by plotting the graph of Predicted values Vs. Actual Values, as shown in Fig-17.

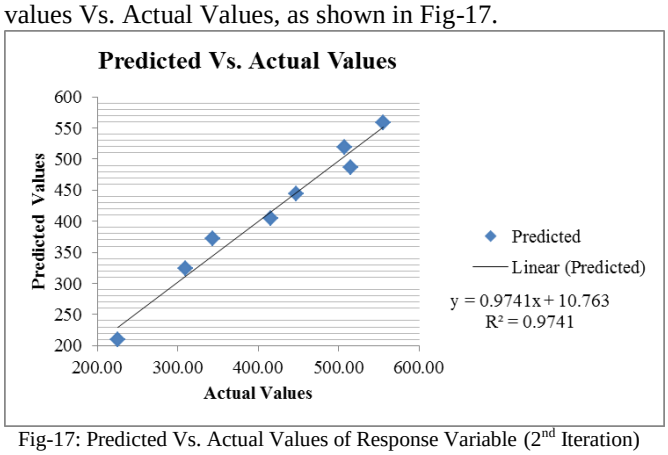

Fig-17: Predicted Vs. Actual Values of Response Variable (2nd Iteration)

The value of R^2=97.41% indicates that, about 97.41% of variation in data is taken care by the regression model. The R^2 (pred.) is 81.57%.

VIII. Conclusions

For finding better operating conditions of TIG Welding, Fractional Factorial Design (FFD) proves to be effective and efficient choice. It not only provides opportunity for screening the significant factors, but also provides optimum result with these variables setting.The latter Regression Model well describes the data, the model suitability checked with Normal Probability Plot and Residuals Vs. Fitted Values Plot. The Regression Model is validated by plotting graph of Predicted Vs. Actual values of Response variable.

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