Modelling and Parametric Optimization using Factorial Design Approach of Tig Welding of AZ61 Magnesium Alloy

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Abstract – Tungsten inert gas welding process is a multi-input and output process in which the resultant joint strength is governed by both individual and combination of process parameters. The identification of suitable combination parameter is crucial to get desired quality of welded joint and hence, there is need for optimization of tungsten inert gas welding process to achieve a sound weldment. The present work is based on the TIG welding process parameters on welding of AZ61 magnesium alloy. The design of experiment is done by Factorial Design approached to find the desired welding conditions for joining similar AZ61 magnesium alloy material. Analysis of variance methods were applied to understand the TIG welding process parameter. The considered parameters are welding current, welding speed, and arc voltage, while the desired output responses are tensile strength and percentage elongation of the welding joints. From the results of the experiments, mathematical models have been developed to study the effect of process parameters on tensile strength and percentage elongation. Optimization is done to find optimum welding conditions to maximize tensile strength and percentage elongation of welded specimen.

Keywords— TIG welding, AZ61 mg alloys material, analysis of variance, Factorial design analysis.

I. INTRODUCTION

In recent year, magnesium alloys have attracted great attention in academic, due to their low density and reduction of weight, high specific strength, stiffness, merchantability and recyclability. Especially for the automobile industry, weight saving effect of replacing steel and aluminium parts with magnesium alloy is an important factor in reducing fuel consumption. [1] Magnesium is the lightest of all the engineering metals, having a density of 1.74 g/cm^3. It is 35% ghter then aluminium (2.7 g/cm^3) and over four times lighter then steel (7.86g/cm^3) [2]. AZ61 magnesium alloy widely used in automobile parts. Different parts of automobile vehicle such as seat frame, steering column housing, lock body and driver air bag housing are attached together by welding [3]. Therefore several type of welding method such as tungsten inert gas (TIG), arc welding, laser beam welding [LBW], and friction stir welding [FSW] have been applied to the welding of magnesium alloy [4]. Compared with other welding method, TIG welding techniques is the quality and performance of welding parts is highly dependent upon the welding process parameters [5]. Thus, many researchers have already applied DOE to optimize welding parameters, but no efforts is yet made to perform this optimization on gas tungsten arc welding of AZ61 magnesium alloy using Factorial design. This study is focused on the Factorial design optimization of some crucial welding parameters namely welding current, welding speed, and arc voltage, to achieve most favorable mechanical properties.

In welding processes, the input parameters influence the mechanical properties of welded joints. Various optimization methods can be applied to define the desired output variables through the development of mathematical models to specify the relationship between the input parameters and output variables. One of the widely used methods to solve this problem is the Factorial design method, in which the experimenter tries to approximate the unknown mechanism with an appropriate empirical model. A few investigation of the effect of TIG welding process parameters and optimization on mechanical and metallurgical properties of aluminium alloy have been reported [5,6]. Very countable number of studies on optimization of pulsed current gas tungsten arc welding process parameters to attain maximum tensile strength in AZ31B magnesium alloy [7]. However there is no information available in open literature on prediction of optimum tungsten inert gas arc welding process parameters to attain maximum tensile strength in AZ61 magnesium alloy joints. Hence, in this investigation an attempt was made to developed an empirical relationship to predict tensile strength of TIG welded AZ61 magnesium alloy joints using statistical tools such as design of experiments, analysis of variance and regression analysis.

II. MATERIALS AND EXPERIMENTAL PROCEDURES

A. *Welding procedure*

Eight pairs of specimens were TIG arc welded based on parameters designed by software Minitab 16. The welding current and arc voltage were measured by using an ammeter and voltmeter. The setup used during the experiments includes shielding gas regular, welding machine was carried out and weld the part by using welding gun and travels with the desired constant speeds along the plates. Each butt weld was formed by three passes of TIG, one over the other. Single butt weld (welded from both sides) preparation was used. Fig.1 shows a schematic representation of the weld joint preparation that was performed by machining. To calculate travel speed, welding length was divided by the welding duration (cm/min). Direct current electrode negative (DCEN) was used preheating and inter pass temperature were 25^0C and 300^0C, The chemical composition and mechanical properties of the base metal are listed in Tables 1 and 2, respectively.

B. *Tensile test*

Tensile test specimen was prepared in according with ASTM standards, shown in Figure 2 [8]. Tensile test were carried out at a strain rate 0.5 s^{-1} by load capacity up to 100KN tensile test machine. In order to ensure repeatability of 0.005% tensile strength. Four samples for each condition were tested.

TABLE1. CHEMICAL COMPOSITION OF AZ61 MG ALLOY

Material	Al	Zn	Mn	Cu	Si	Fe	Ni
AZ61	5.8 ~ 7.2	0.4 ~ 1.5	0.15 ~ 0.5	≦0.05	≦0.1	≦0.005	≦0.005

TABLE2. MECHANICAL PROPERTIES OF AZ61 MG ALLOY

Yield stress (Mpa)	Tensile test (Mpa)	Elongation (%)
234	325	22

III. FACTORIAL DESIGN APPROACH AND TERMINOLOGY

Factorial design planning is simply applied to determine and represent the cause and effect relationship between true mean responses and input control variables influencing the responses. Three kinds of design of experiments [5,12] are possible between output and input variables.

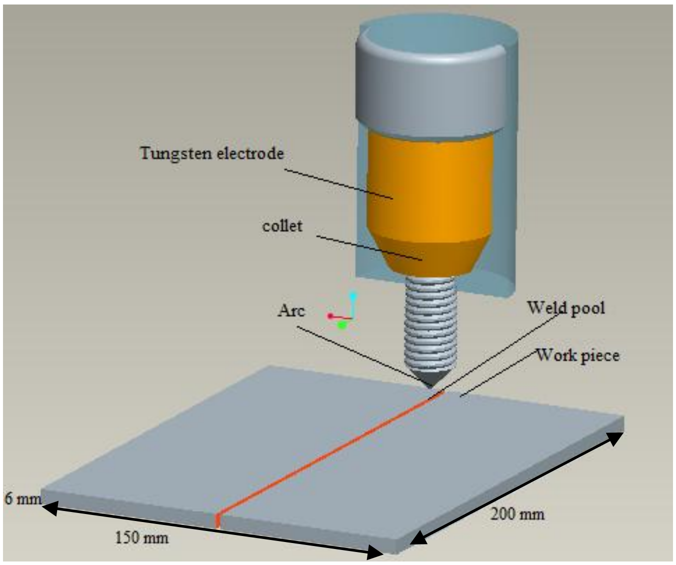

Fig.1. Schematic of the TIG welding process by using Pro-e model

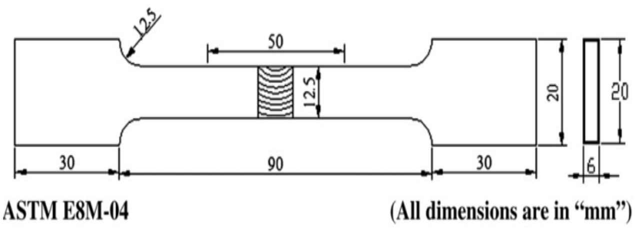

Fig.2. Dimension of flat smooth tensile specimen

1. Screening designs are used in beginning of process where more than five factors are involved, to recognize the most critical factors.
2. Characterization deigns narrow the numbers of factors to only a few and permit for some quantitative understanding of the interactions among factors.
3. Optimization designs focus on only one or three factors, but in much more joining strength to understanding of relationships between factors

A full Factorial design combines the levels for each factor with all the levels of every factor. It covers all combinations and provides best data. However it consumes more time and resources. While a fractional Factorial design, uses too many of resources, or if a slightly non orthogonal array is accepted a fractional design is used. To analyse the data from a design of experiment, evaluating the statistic significance by computing one way ANOVA, or for more than one factor N-way ANOVA is essential. The practical significance can be evaluated through sum of squares, line or column charts, and normal probability chart.

IV. METHODOLGY

The work to be carried out was planned in the following order:

1. Identification of important process variables;
2. Finding different levels of the identified process variables;
3. Development of design matrix;
4. Conducting experiments as per the design matrix;
5. Recording the responses, viz. Tensile strength and Percentage elongation,
6. Development of mathematical model
7. Calculation of regression coefficients
8. Checking the adequacy of the developed model
9. Development of final mathematical model by testing the significance of regression models
10. Presenting the main and significant interaction effects of process parameters on bead penetration, and bead width and weld reinforcement of Butt weld.

A. Identification of operating variables

Selection of process variables has considerable influence on the weld quality, and Tensile strength [7]. Table3 shows independent controllable process variables, which were identified based on their significant effect on weld joint to carry out the experiments.The extrude plate of 6mm thickness, AZ61 magnesium alloy were cut to the required dimension (150mm ×200mm) by power hacksaw cutting and milling. The initial joint configuration was obtained by securing the plates in position to mechanical clamp. The direction of welding was normal to the rolling direction. Argon (purity 99.99%) was used as shielding gas. The welding rod was used an ESAB.SAI, 3.15mm diameter with electrode to be working angle $30^{o.}$

TABLE3. IMPORTANT TIG WELDING PARAMETERS AND THEIR WORKING RANGE

Parameter	**Notation**	**Level**	
		-1	**1**
Welding current	I	120	160
Arc voltage	V	8	22
Welding speed	S	30	180

B. Finding different levels of the identified process variables

The levels for each factor were the highest value and the lowest value of the factors in between and at which the outcome was acceptable. These values were outcomes of trials runs. Highest value has been represented by "" and middle value has been represented "0" the lowest value has been represented by "-1" as mentioned in Table 4.

C. Development of design matrix

For conducting trial runs levels of these values were chosen randomly such that sampling fraction for these trials run was equal to zero, however rough range was taken from literature survey [8]. With the help of these trials run effective, representative levels were developed for each variable. The factorials are also known as 2-k factorials, where 2 is the number of levels and k is no of important process variables [9]. For full Factorial approach number of runs are equals to 2_k whereas for half factorial or fractional factorial number of runs are equal to 2_{k-1}. If full Factorial approach had been practiced then number of possible runs will be 2^3 i.e. 8. Full factorial approach had been applied according to which the number of treatment combinations becomes 2^{**3} $(2^{**3} = 8)$.

Table4-Design matrix and their responses

S. No	Design matrix			Tensile strength	% elongation
	I	S	V		
1	-1	-1	-1	125.0	4.23
2	1	-1	-1	160.0	5.55
3	-1	1	-1	112.1	6.12
4	1	1	-1	145.5	5.80
5	-1	-1	1	132.5	5.70
6	1	-1	1	95.8	5.25
7	-1	1	1	153.3	3.42
8	1	1	1	104.6	5.95

C.*Mathematical Model Developed*

Assuming the values of responses as y_1, y_2, y_3, y_4, y_5, y_6, y_7, y_8 against the treatment combinations 1, 2, 3, 4, 5, 6, 7, 8 respectively Y as the optimized value of response. The response function represents any of the weld dimensions can be expressed as the following equation:

Y = f (I, V, S,) and the relationship selected, being a second degree response surface, expressed as follows:

$Y = b_0 + b_1I + b_2V + b_3S + b_{12}(IV) + b_{13}(IS) + b_{23}(VS)$ (1)

D. Evaluation of coefficient of models

The values of the coefficient ware calculated with the help of following calculations:

TABLE 5 ESTIMATED VALUE OF THE COEFFICENT OF THE MODELS

S. no	Coefficient	Tensile strength	% Elongation
1	b_0	129.09	5.2525
2	b_1	-2.64	0.3850

3	b_2	0.76	0.0700
4	b_3	6.54	-0.1725
5	b_{12}	-19.71	0.1350
6	b_{13}	7.64	-0.4650
7	b_{23}	-1.79	0.5775

b0 = [(y1+y2+y3+y4+y5+y6+y7+y8)]/8

b1 = [(y5+y6+y7+y8)-(y1+y2+y3+y4)]/8

b2 = [(y3+y4+y7+y8)-(y1+y2+y5+y6)]/8

b3 = [(y3+y4+y5+y6)-(y1+y2+y7+y8)]/8

b12 = [(y1+y2+y7+y8)-(y3+y4+y5+y6)]/8

b13 = [(y1+y2+y3+y4)-(y5+y6+y7+y8)]/8

b23 = [(y1+y3+y6+y8)-(y2+y4+y5+y7)]/8

The values of different coefficients for different responses were calculated as per the modelling as given in table 5. These values of coefficients represent the significance of corresponding variable on the response [10]. Higher value of coefficients signifies higher influence of the variable on the response. Inverse relationship between variable and response is found when the value of coefficient is negative.

E. Checking the adequacy of models developed

The estimated value of the coefficient of the model indicates as to what extent the important process variables affect the responses quantitatively [11]. The result through analysis of variance as given in Figures 2, 3and 4 shows that welding current and arc voltage has the significant parameters that affect Tensile strength while welding speed has little effect on percentage elongation .

Similarly ANOVA is carried out for other weld parameters, which shows that welding current and welding speed have major influence on tensile strength whereas arc voltage has minor effect. Weld reinforcement is equally influenced by welding current and arc voltage. The value of F-ratio for a desired level of confidence (95%) was achieved that indicated model may be considered adequate within the confidence limit.

F. Development of the final models

The final mathematical model as determined by the above analysis can be represented by following equation:

UTM = 129.09 – 2.64I + 0.76V + 6.54S – 19.71IV +7.64IS – 1.79VS (2)

% = 5.2525 + 0.3850I +0.0700V – 0.1725S + 0.1350IV – 0.4650IS + 0.5775VS (3)

G. Analysis of the results

In fig 3, 4 and 5 main and significant interaction effects of process parameters on tensile strength and percentage elongation are plotted.

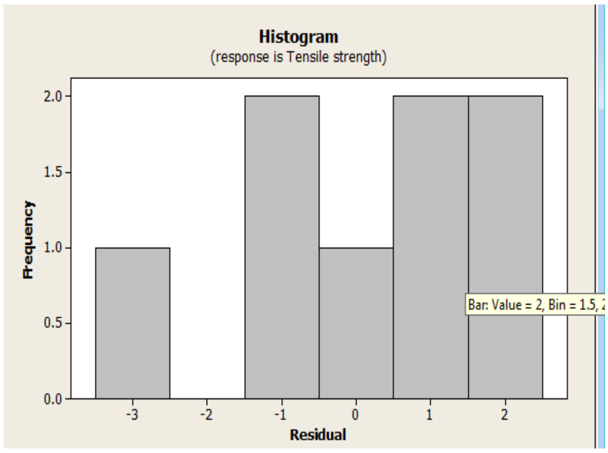

Fig 3 Histogram response is tensile strength

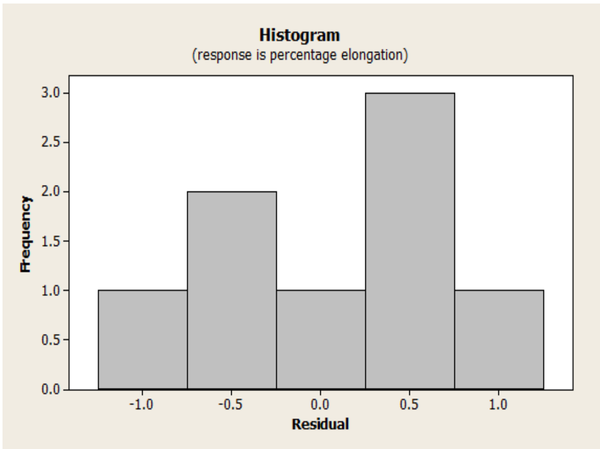

Fig 4 Histogram response is percentage elongation

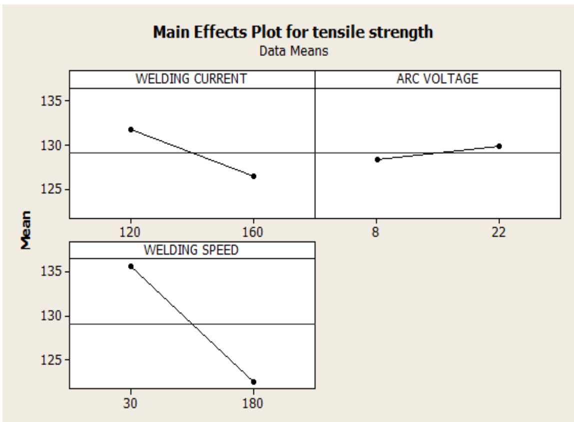

Fig 5 Main effect plot for tensile strength

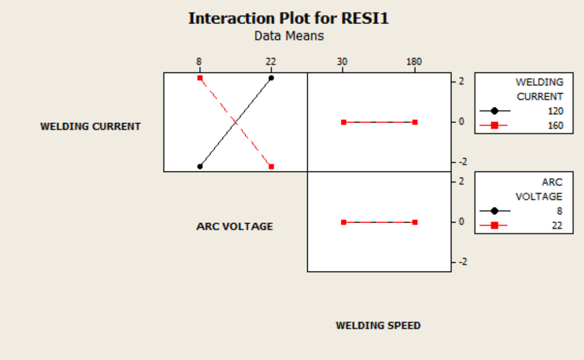

Fig 6 Interaction plot for RESI1

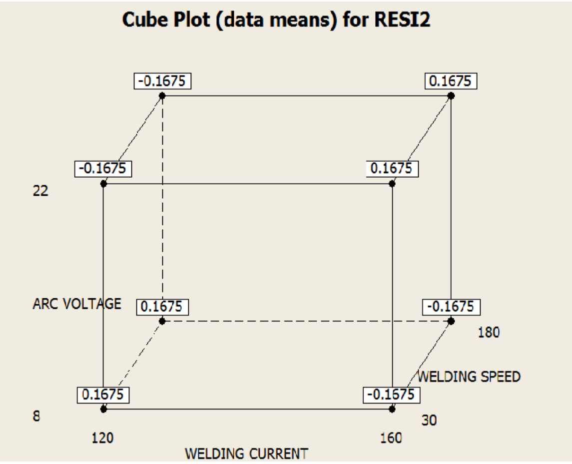

Fig 7 Cube plot (data means) for RESI2

E. Conclusion

The effect of TIG welding parameters like welding speed, current and arc voltage, on ultimate tensile strength and percent elongation in welding of AZ61 magnesium alloy has been studied. Experiments were conducted using Full factorial design matrix and mathematical models have been developed. From the study it was observed that welding speed has the most significant effect on both UTS and percent Elongation followed by welding current. However gas flow rate has least significant influence on both UTS and percent elongation. Optimization was done to maximize UTS and percent elongation. Predicted properties at optimum condition are verified with a confirmation test and are found within the limits.

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