

Effect of process variables on the tensile shear strength of spot welds in 6061-T6 aluminum alloy

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ABSTRACT – The changes in mechanical and metallurgical behavior of spot welded region generally occur throughout the spot welding process and these changes are very significant for the safety and quality of the welded joints. Due to the influence of current flow, the squeezing time and the load applied on electrodes have a vital effect on the mechanical properties. This paper presents the effect of such parameters on the tensile shear strength of single lap spot welded 6061-T6 aluminium alloy. Two level four factor fractional factorial design was employed to develop mathematical models. It was found that change in weld thickness and current are the primary parameters that control the tensile shear behavior of the spot welds.

1. INTRODUCTION

Employing light materials such as aluminium and magnesium alloys as an alternative for steel is the need of the hour for the ‘all-time’ competitive automotive industry to survive, in terms of the growing energy and environmental regulations of the modern world. Aluminum alloy 6061-T6 is a widely used structural material for automobile, air craft and maritime industries since it is highly weldable and has favorable mechanical properties [1-3]. Since the resistance spot welding (RSW) is the most widely used process for the fabrication of automobile case parts due to its simplicity, low-cost, high production rate and automation accessibility [4], it is critical to understand the behavior of the welding process control parameters on the mechanical properties of the aluminum 6061-T6 alloy.

2. METHODOLOGY

2.1 Development of Design Matrix

After a series of trial runs, the experimental design matrix was developed in accordance with the design of experiments (DOE) methodology, by adopting a two level, four factor fractional factorial design ($2^{4-1}=8$) of eight runs. For a factorial design of experiment, it is crucial to select the “individually controllable” process control parameters which are generally selected either from the published literature or the trial runs. For the present study the electrode force (F), weld current (I), weld time (t) and work piece thickness (w) were selected as the four main parameters that influence the

tensile shear strength, the response parameter to be evaluated. All the direct and indirect parameters involved in the RSW process were kept constant. The upper limit (highest level) and the lower limit (lowest level) of a factor were coded as (+1) and (-1) or simply (+) and (-) respectively according to the equation (1).

$$X_j = \frac{X_{jn} - X_{jo}}{J_j} \quad (1)$$

Where, X_j is the coded value of the factor; X_{jn} is the natural value of the factor; X_{jo} is the natural value of the basic level; J_j is the variation interval and j is the number of the factors. The selected process control parameters, their units, symbols and the limits are given in Table 1.

Table 1 Selected process control parameters and limits

Parameter	Unit	Symbol	Limits	
			High (+1)	Low (-1)
Force	kN	F	1.8	1.2
Current	kA	I	26.6	23.8
Weld Time	cycle	t	8	3
Thickness	mm	w	1	0.71

2.2 Experimentation

In the present work, a pedestal spot welder, Lecco -Italia NKLT(P) 28 was used. Prior to the experiments, all the critical process control parameters were calibrated.

Table 2 Design matrix for calculating the coefficients

S.	β_0	β_1	β_2	β_3	β_4	T_s'	T_s''	T_s'''
1	+	+	+	+	+	30.63	34.79	32.71
2	+	-	+	+	-	76.29	78.35	74.24
3	+	+	-	+	-	51.79	52.52	53.26
4	+	-	-	+	+	42.03	43.85	40.21
5	+	+	+	-	-	76.29	84.65	67.93
6	+	-	+	-	+	51.41	55.00	47.81
7	+	+	-	-	+	28.96	34.27	31.61
8	+	-	-	-	-	61.25	55.60	66.90

For welding current - digital multimeter; for electrode force- SP-231N Spotron hydraulic weld force gauge and for welding time – Casio digital stop watch were employed. The experiments were performed as per

the design matrix in a random way by using the table of random numbers to remove any systematic error of experiment to produce set of three welding current columns. Three replications of experimental data were collected for statistical modeling requirements and are tabulated along with the design matrix in Table 2.

2.3 Selection and Development of Mathematical Model

A linear model of the type $Q = f(F, I, t, w)$ was adopted for the study which can be written in the form of a polynomial by taking into account all the possible two factor interactions as:

$$T_s = \beta_0 + \beta_1 F + \beta_2 I + \beta_3 t + \beta_4 w + \beta_{13} tw + \beta_{14} Fw + \beta_{23} It + \beta_{24} Iw + \beta_{34} tw \quad (2)$$

Where T_s is the measured tensile shear strength, the response parameter, $\beta_0, \beta_1, \dots, \beta_4$ are the linear coefficients to be estimated which depend on the four process control parameters. The proposed model was developed by regression analysis, whose adequacy and the significance of its coefficients were tested by the analysis of variance (ANOVA) technique and Student's 't' test. The regression coefficients of the model were calculated using the method of least squares.

3. RESULTS AND DISCUSSION

3.1 Main and Interaction Effects

The proposed model for prediction of the tensile shear strength (T_s) of the aluminum 6061-T6 alloy after neglecting the statistically insignificant parameters is given by

$$T_s = 53.01 - 4.73F + 6.61I - 2.13t - 13.57w - 3.54Ft - 2.55Fw \quad (3)$$

From the mathematical model (3) it can be seen that all the four process variables considered for the study, the electrode force (F), weld current (I), weld time (t) and work piece thickness (w) control the tensile shear strength. The weld current has positive effect while the rest have inverse effect on T_s as shown in the surface plot in Figure 1.

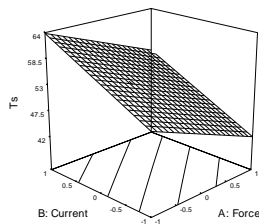


Figure 1: Surface plot on the effect of electrode force and current on tensile shear strength

It is well known that weld current is responsible for the heat input in arc welding [5]. An increase in weld current will increase the heat input resulting more melting and with pressure the atoms of the faying surfaces will be made closer enough to increase the joint strength. However the increase in welding force, time and dissimilar thickness at the same current level as per the model would decrease the tensile shear strength of the weld joint. Work piece thickness is proportional to

the total resistance and need more current to perform melting and hence joining. Also an increase in electrode force will lead to indentation and splashing. The increase in weld time leads to overheating. Both of these reduce the joint strength. The model also showed that the welding force combining with the weld time (Figure 2) and change in workpiece thickness have significant interaction effects on the tensile shear strength as well. An increase in either of the electrode force, time and thickness will have an adverse effect on the strength of the joint.

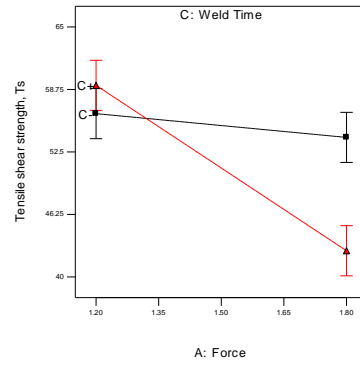


Figure 2 Interaction plot on the effect of electrode force and weld time on tensile shear strength

4. CONCLUSIONS

A mathematical model was developed to predict the effects of electrode force (F), weld current (I), weld time (t) and dissimilar work piece thickness (w) on tensile shear strength of aluminum 6061-T6 alloy spot welds. It was found that the weld current has direct relationship with the tensile shear strength while the rest have an inverse relationship. The welding force along with weld time and thickness has significant interactive influence causing an inverse effect on the tensile shear strength. The two level fractional factorial technique is found to be adequate and effective in predicting the main and interactions effect of the process control parameters on the tensile strength for resistance spot welds.

5. REFERENCES

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