Determination of Weld loads by using Design of Experiments for low carbon steel sheet for Automobile Application

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Abstract--Resistance welding is now an established mass production process and widely used for assembly of sheet metal. Two sheets are welded together at points, rather than entire area of contact between the parts. New concept namely indirect resistance spot welding was developed for applications where the surface appearance on sheet can be critical. In this process outer surface, limiting the extent of electrode indentation is traditionally managed by controlling the heat balance and electrode size.

Design of experiment approach where 2³ factorial designs were used. The three factors selected are weld force weld current and weld time and each factor was varied with two Levels. Tension shear load were taken for response.

Direct and indirect resistance spot welding trials were conducted and regression equations were obtained. The effect of parameters on Tension shear breaking load was analyzed. The observations on Tension shear load were discussed. Failure behaviour was analyzed after every test. Since spot welds during service are expected to perform well under different loading conditions these results will be useful for optimum design.

Keywords-- Direct Resistance spot welding, Indirect Resistance spot welding, or one side spot welding, Tension shear load, sheet metal fabrication.

I. INTRODUCTION

About direct resistance spot welding:

Spot welding is now an established technique and widely used for assembly of sheet metals. Two sheets are welded together at points, rather than over the entire area of contact between the parts. Cylindrical electrodes apply pressure and convey electrical current to the work pieces. The contact resistance at the metal interface is very important to decide the quantum of heat required for melting of specified volume.

Indirect resistance welding is the resistance welding process where the weld force and weld current are transmitted by different electrodes [1]. While the weld force is applied in a similar manner as traditional direct RSW, the weld current is directed along a different path so that a critical interface can be excluded from the current path and heating reduced on one side of the sheets. This can be achieved by grounding the current path through another electrode that has good contact with the work sheets. Fixture and location jig can be used to redirect the current path away from the critical interface.

Fig. 1 Schematic diagram showing direct resistance spot welding process (DRSW)

Fig. 2 Schematic diagram showing indirect resistance spot welding process. (IRSW).
The top electrodes apply the weld force, and conduct the weld current through the top sheet and interface, and then are grounded through the tertiary electrode.

Spot weld made by resistance welding has been widely used in joining sheet metal in ground vehicle industry. Although the spot weld has been used maximum, a simple failure criterion that is able to predict the failure strength of a spot weld subjected to various loading conditions does not exist.

Conventional process or practice in industry is to perform extensive tests obtain sufficient data sets for design approach purpose. The variables to consider such as welding parameters, thickness, and nugget size and for given materials.

To develop and analysis the failure mechanisms or criterion of spot weld for direct and indirect resistance spot welding we performed the strength test using lap – shear, samples made for low carbon steel sheet for fabrication which are used very extensively in automobile industry for most of applications.

Observation during the tests reveals the type of joint failure at the nugget i.e., around the HAZ from peel test the failure mechanisms are identified.

Performed lap- shear sample is subjected to shear load at the structural level failure mechanism at the spot weld is tensile mode at the material level [2]. Based on the observed failure mechanism, stress distribution is assumed and related to the field load for the lap shear and cross tension samples. It appears that the failure load of the cross tension sample is 74% of the lap shear sample based on classical von Mises failure theory.

Performed, the effect of weld time on the tensile – peel strength and Tensile- shear strength of welding joints in electrical resistance spot welding of chromat micro alloyed steel sheet having 1.2 mm thickness were investigated [3]. The welding joints were exposed to tensile- peel and tensile- shear tests and effect of the welding time on tensile peel strength and tensile- shear strength was researched by using related period diagrams.

To develop the failure criteria of the direct and indirect spot welds, the strength test using tension shear were performed, samples made for the low carbon steel sheet. Based on the failure strength results of the spot welds established.

II. EXPERIMENTAL WORK – TENSION SHEAR TEST

Equipment

Trials were conducted on a 10 KVA Spot welding machine (3– Phase, 415 Volts, 50Hz.). This machine has a provision for adjustment of two levels of load with mechanical system. Six voltage tap settings are available for setting secondary voltage. A weld timer controls duration of current flow (Fig.5).

Material

Experiments were carried out on cold rolled carbon steel (CRCS). AISI – C1010 sheets, of 0.6 mm thickness which is having very good applications for thin sheet fabrication. The chemical composition and mechanical properties are given in table-1 and 2.

Factorial design

Experiment was carried out by using $2^3$ factorial design. The three factors are weld force in kgf – $X_1$, weld time in Amps – $X_2$, and each factor was varied with two levels. Experimental design levels for the factors are given in table – 3.

III. RESULTS AND DISCUSSIONS

Experimental observations, in coded- matrix form are given in tables 4 and 5 and Figures 3 and 4 for the treatment combinations conducted for direct and indirect spot welding, where + ve and - ve values denote higher and lower levels of the corresponding parameters. Also corresponding responses (Breaking load or Tension shear load ) are given for each treatment combination. To analyze the experimental data, a simple linear regression equation for response, has been assumed and is given by,

$$Y = Y_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_1X_2 + b_5X_1X_3 + b_6X_2X_3 + b_7X_1X_2X_3$$

By applying the method of least square to the data of table 6 and 7 the co-efficient $b_i$ were calculated.

$$\bar{Y}_0 = \bar{Y}_0$$

high ~ low  / (n/2) , for single set of trials, the ‘$b_i$’ values are tested for significance and were substituted in the equation, Where “$n$” is the number of treatment combinations (n = 8).

$$Y = Y_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_1X_2 + b_5X_1X_3 + b_6X_2X_3 + b_7X_1X_2X_3$$

Positive coefficients of any factor indicate that in increasing this variable, would enhance the response, negative coefficients the opposite. The standard deviation was calculated from experimental values using the expression.

$$\bar{Y} = \frac{1}{n} \sum (Y - Y_0) / (n - 1) \quad , \quad (y_0 \text{ is the average response value})$$

As per test of significance F (2, 7) = 4.74 considering degree of freedom for error 2 and 7 for treatment combination the test of significance was carried out (obtained from statistical tables). Hence above 4.74 all the regression Co-efficient have greater significance. Accordingly the regression equation obtained is given as:
Y = 175 +11X_1 - 15X_2 + 6.5 X_1X_3 - 7X_2X_3 + 10 X_1X_2X_3  (For IRSW)

Y = 330 +5X_1 +125X_2 + 80 X_1+65X_2 +42.5 X_1X_3+102.5X_2X_3 + 70 X_1X_2X_3  (For DRSW)

**Influence of weld parameters for the direct resistance spot welding (DRSW)**

From table -6, as per the Regression equation and its co-efficients of direct spot welding, the influence of weld current (X2) was found to be more significant (β_2 = 125), the interaction of weld current (X2) and weld time ( X3) also were significant (β_23 = 102.5) when compared to weld force (β_1 =5), and interaction of weld force, weld current and weld time (β_123 = 70) .

**Influence of weld parameters for the indirect resistance spot welding (IRSW)**

From table -7, as per the regression equation and its co-efficients for indirect spot welding the influence of weld force (X1) is more significant (β_1 = 11), the interaction influence of weld force (X1) and weld time (X3) also were more significant (β_13 = 6.5) and, interaction of weld force, weld current and weld time (β_123 = 10) also were found to be significant.

**IV. CONCLUSION**

Direct spot welds under optimum welded conditions with in the range selected by design of experiments gave very good tension- shear breaking loads.

Indirect spot welding carried out by using the specially designed tooling revealed satisfactory welds could be obtained for 0.6mm thick cold rolled carbon steel.

Though the tension- shear breaking loads are lower for indirect spot welds (for the optimum conditions with in the range selected) the using design of experiments and the magnitude of load are adequate for majority of Industrial applications. This is confirmed as by peel test results.

The indentation obtained for indirect spot welding on one side of the sheet is negligible and is satisfactory for any type of painting requirements. This also gives good appearance.

It is concluded that the design of experiments approach was very effective in finding the optimum welding conditions for both direct and indirect spot welds.

**Acknowledgement**

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**REFERENCES**


**Table 1**

<table>
<thead>
<tr>
<th>Element</th>
<th>Chemical composition for specimen (AISI, C- 1010) -Cold rolled carbon steel (CRCS)</th>
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<tr>
<td>C</td>
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</tr>
<tr>
<td>Mn</td>
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**Table 2**

<table>
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<th>Details of properties</th>
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<td>1</td>
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<td>2</td>
<td>yield stress</td>
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<td>3</td>
<td>Shear strength</td>
<td>15 kg/mm2</td>
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<tr>
<td>4</td>
<td>Elongation</td>
<td>32 – 48%</td>
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Welding parameters in factorial design of experiment for direct (DRSW) and indirect (IRSW) resistance spot welding.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Welding parameters</th>
<th>Factor designation</th>
<th>Design levels</th>
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<tr>
<td></td>
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<tr>
<td>3</td>
<td>Weld Time - Sec</td>
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<td>0.1 Sec (5 cycles)</td>
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Experimental observations in coded - matrix form and parameters for direct resistance spot welding (DRSW):

<table>
<thead>
<tr>
<th>S. No</th>
<th>Weld Force X1 (Kgf)</th>
<th>Weld current X2 (Amps)</th>
<th>Weld Time X3 (Sec)</th>
<th>Tension shear Breaking load (Kgf)</th>
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</tr>
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<td>-1</td>
<td>+1</td>
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</tr>
<tr>
<td>4</td>
<td>+1</td>
<td>-1</td>
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</tr>
<tr>
<td>7</td>
<td>-1</td>
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Experimental observations in coded - matrix form and parameters for indirect resistance spot welding (IRSW):

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<th>Weld current X2 (Amps)</th>
<th>Weld Time X3 (Sec)</th>
<th>Tension shear Breaking load (Kgf)</th>
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<td>-1</td>
<td>-1</td>
<td>190</td>
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<td>2</td>
<td>+1</td>
<td>-1</td>
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<td>252</td>
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### Table 6

Regression equation and coefficients for direct spot welding (DRSW)

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<th>Trial</th>
<th>Factors</th>
<th>Tension shear breaking load (Y)</th>
<th>Treatment combinations</th>
<th>Coefficients</th>
<th>Values</th>
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<td>250</td>
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<tr>
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<td>X2=2400</td>
<td>0.1</td>
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<td>300</td>
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<td>6</td>
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<td>0.3</td>
<td>240</td>
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<tr>
<td>7</td>
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<tr>
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**Remark:** The values 125 and 102.5 indicate the influence of weld current and weld time.

### Table 7

Regression equation and coefficients for indirect spot welding (IRSW)

<table>
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<tr>
<th>Trial</th>
<th>Factors</th>
<th>Tension shear breaking load (Y)</th>
<th>Treatment combinations</th>
<th>Coefficients</th>
<th>Values</th>
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<tr>
<td>4</td>
<td>X1=45</td>
<td>X2=2400</td>
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</table>

**Remark:** The values 11, -1.5, and -7 indicate the effect of weld force, weld current, and weld time, respectively.

**Standard deviation:**

![Standard deviation formula]

Note: General equation and calculation methodology for coefficients:

\[
Y = Y_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_1 X_2 + \beta_5 X_1 X_3 + \beta_6 X_2 X_3 + \beta_7 X_1 X_2 X_3
\]

\[
\beta_0 = \overline{Y_{\text{high}}} - \overline{Y_{\text{low}}} / (n/2), \quad \text{for single set of trials, } \overline{Y_{\text{high}}} = Y_2 + Y_4 + Y_6 + Y_8 \quad \text{and } \overline{Y_{\text{low}}} = Y_1 + Y_3 + Y_5 + Y_7
\]

\[
\overline{Y} = \frac{(Y - Y_0)^2}{n - 1}, \quad Y = Y_0 = \overline{Y_{\text{low}}} + \overline{Y_{\text{high}}} n, \quad Y = \text{tension – shear load, } \beta = \text{coefficients}
\]

\( n \) = number of trials, Test of significance \( F(2, 7) = 4.74 \) (from statistical tables)

\( Y = 175 + 11X_1 - 15X_2 + 6.5X_1X_3 - 7X_2X_3 + 10X_1X_2X_3 \) (For IRSW)

\( Y = 330 + 5X_1 + 125X_2 + 80X_3 + 65X_1X_2 + 42.5X_1X_3 + 102.5X_2X_3 + 70X_1X_2X_3 \) (For DRSW)
Fig. 3, 4 Specimen samples of direct and Indirect resistance spot welding (DRSW)&(IRSW)

Fig. 5 10KVA spot welding machine