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Investigation of the Effect of Weld Parameters of Direct Resistance Spot Welds made on AISI, C1010 Cold Rolled Carbon Steel Sheet for Auto Applications

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Abstract: *All resistance welding processes are based on the heat that is produced at the interface due to resistance for the flow of electric current through the metal parts being joined. The amount of heat generated basically depends on the magnitude of the current, the duration of current flow and the load transmitted to the inter face.*
Spot welding is now a very established process in which two sheets to be welded are kept one over the other to get a nugget at the interface. The contact resistance at the interface dictates the quantum of heat that is generated
In the present investigation, AISI,C1010 (Cold rolled carbon steel sheet, were welded by resistance spot welding.
Trials were conducted using "statistical "design of experiments approach where 2^3 factorial designs was used. The three factors selected are weld force, weld current, and weld time. Each factor was varied with two levels and the tension shear load was taken as response criteria. Direct resistance welding trials were conducted and regression equations were obtained. The effect of parameters on tension shear breaking load was analyzed.
Keywords: *Resistance Spot Welding, Nugget Diameter, Tensile Strength, Peel test*

I. Introduction

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. Resistance Spot welding is extensively used in automobile sector due to high level of flexibility, rate of production, high quality and low cost of operations. Vehicle components (body, doors etc) are made of thin sheets (0.5 to 1 mm) connected by spot welds. There are other applications in electrical and domestic appliances. The process details of direct spot welding process are shown in figure 1.

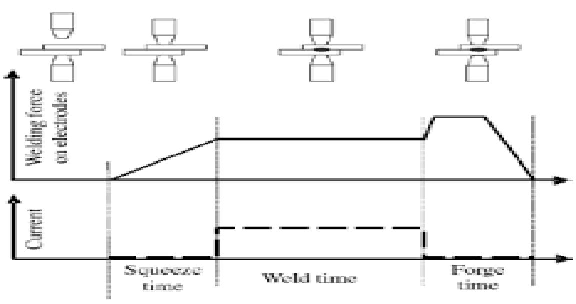

Fig. 1 Schematic diagram showing direct resistance spot welding process

II. Experimental work

2.1 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 (see fig. 3).

2.2 Material

Experiments were carried out on cold rolled carbon steel (CRCS), AISI – C1010 sheets, of 0.8 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.

2.3 Tension – shear test specimen

Spots were made on sheets 0.8 mm thick 25mm width 75 mm length specimens. The same specimens were used for tension- shear testing. (See fig.5).

2.4 Factorial design

This experiment was carried out by using 2^3 factorial design .The three factors are weld force in kgf – X1, weld current in Amps – X2, weld time in seconds – X3, and each factor was varied with two levels. Experimental design levels for the factors are given in table-3

2.5 Tension – shear test

The specimens were gripped in a specially designed fixture to determine the tension shear load using a 40 T-UTM (see fig.4 & 6).

2.6 Peel test

The specimen was tested by peel test using a bench vice and tongs. The nugget formation was observed for both direct and indirect spot welding. The nugget sizes were determined and the position of failure was noted. (See fig.8)

2.7 Experiment inputs and out puts

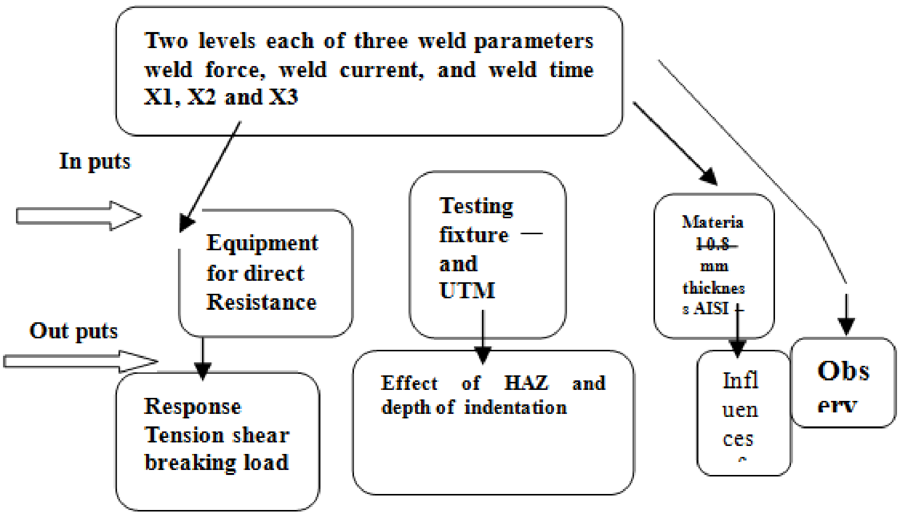

Fig.2 Over view of Design of experiments

III. Results and discussions

Experimental observations, in coded- matrix form are given in table-4 and figure -5for the treatment combinations conducted for direct 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,

$$Y = Y_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{123} X_1 X_2 X_3.$$

By applying the method of least square to the data of table - 4 the co-efficient βi were calculated.

$\beta_i = \Sigma Y_{high} - \Sigma Y_{low}$ / (n/2), for single set of trials, The ‘β” values are tested for significance and were substituted in the equation ,Where “n” is the number of treatment combinations (n = 8).

$$Y = Y_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{123} X_1 X_2 X_3$$

Positive coefficients of any factor indicate that in increasing this variable, would enhance the response, negative coefficients the opposite.

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:

$Y = 276.25+8X_1 +110.5 X_2+ 60 X_3+59.25X_1X_2 + 34 X_1X_3+85.25X_2X_3 + 57.5 X_1X_2X_3$

Peel test was done to find qualitatively, the formation of nugget and nature of failure. These results were shown in table -7and the Figure.8.

Table -6 gives the results of (d/t) ratio as per design requirements of the direct resistance spot welding. Table- 9 gives the observations of depth of electrode indentation on top and bottom sheet and Table- 8 gives the details of HAZ observations.

3.1 Influence of weld parameters.

From table 5 ,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 = 110.5) , the interaction of weld current (X2) and weld time (X3) also were significant (β_{23} = 85.25) when compared to weld force (β_1 =8), and interaction of weld force, weld current and weld time (β_{123} = 57.5) .

3.2 Observation of d/t ratio

The design of spot weld requires control of the ratio of weld diameter to the sheet thickness, d/t = 1.28 X yield stress / shear stress [11] and (appendix 8.1, 8.2, and 8.3). Table - 6, give the results as per design requirement and experimentation by peel of test. The direct spot welding gave (d / t) ratio, observed more safe design.

with in 0.1 maximum and HAZ is varying from 0.1 to 0.5 maximum for each sample. Both parameters are almost consistent for all the conditions of weld parameters.

3.3 Effect of nugget diameter: The nugget size is proportional to weld current and time, The nugget sizes measured after peel test revealed satisfactory results and are adequate for several applications.

IV. Conclusion

1. Direct spot welds under optimum welded conditions within the range selected by design of experiments gave very good tension- shear breaking loads for 0.80 mm thickness.
2. It has been observed from the experiments results and the magnitude of load is adequate for majority of Industrial applications. This is confirmed by (d/t) ratio calculations as well as by peel test results.
3. Reveled from the results the design value will be considered as 85 Kgf for auto applications.
4. Observed the depth of indentation for top and bottom surfaces are within 10% of thickness. Maximum
5. It is concluded that the design of experiments approach was very effective in finding the optimum welding conditions.

Table 1: Chemical composition for specimen (AISI, C- 1010) - Cold rolled carbon steel (CRCS)

Element	C	Mn	P	S
Weight Percent (%)	0.1max	O.25-0.5	0.04max	0.05max

Table 2: Mechanical properties of specimen

S. No	Details of properties	Units
1	UTS	30 kg/ mm2
2	yield stress	21kg/mm2
3	Shear strength	15 kg/mm2
4	Elongation	32 – 48%

Table 3: Welding parameters in factorial design of experiment.

S. No	Welding parameters	Factor designation	Design levels	
			Lower (-1)	High (+1)
1	Weld Force-Kgf	X_1	30	45
2	Weld Current-Amp	X_2	1800	2400
3	Weld Time – Sec	X_3	0.1 Sec (5 cycles)	0.3Sec (15cycles)

Table 4: Experimental observations in coded - matrix form and parameters.

S. No	Weld Force X1 (Kgf)	Weld current X2 (Amps)	Weld Time X3 (Sec)	Tension shear Breaking load (Kgf)
1	-1	-1	-1	170
2	+1	-1	-1	229

3	-1	+1	-1	314
4	+1	+1	-1	272
5	-1	-1	+1	285
6	+1	-1	+1	220
7	-1	+1	+1	340
8	+1	+1	+1	400

Table 5: Regression equation and coefficients

Trial	Factors			Tension shear breaking load (Y)	Treatment combinations	Coefficients	Values
	X1	X2	X3				
1	30	1800	0.1	170	1		
2	45	1800	0.1	229	X_1	$\square_1$	8
3	30	2400	0.1	314	X_2	$\square_2$	**110.5-weld current**
4	45	2400	0.1	272	X_1X_2	$\square_{12}$	59.25
5	30	1800	0.3	285	X_3	$\square_3$	**60 - Weld time**
6	45	1800	0.3	220	X_1X_3	$\square_{13}$	34
7	30	2400	0.3	340	X_2X_3	$\square_{23}$	**85.25–weld current and weld time**
8	45	2400	0.3	400	$X_1X_2X_3$	$\square_{123}$	57.5

Note: General equation and calculation methodology for coefficients:

$Y = Y_0 + \square_1X_1 + \square_2X_2 + \square_\square X_3 + \square_{12}X_1X_2 + \square_{13}X_1X_3 + \square_{23}X_2X_3 + \square_{123}X_1X_2X_3\square$

$\square\ \square\ \square = \square\ \square_{high} - \square\ \square_{low}$ / (n/2) , for single set of trials, $\square\ \square\ \square_{high} = Y_2 + Y_4 + Y_6 + Y_8$ and $\square\ \square_{low} = Y_1 + Y_3 + Y_5 + Y_7$

Y = tension – shear load , β^r = coefficients , n = number of trials ,Test of significance F (2, 7) = 4.74 (from statistical tables)

$Y = 276.25 + 8X_1 + 110.5\,X_2 + 60\,X_3 + 59.25X_1X_2 + 34\,X_1X_3 + 85.25X_2X_3 + 57.5\,X_1X_2X_3$

Table 6: Observations of d/t ratio

Yield stress as per AISI 1010	As per design requirement	As per experiment by peel test
	d/t Ratio	**d/t Ratio**
21 kg/mm2 (maximum)	0.9	2.7 / 0.8= 3.4 (considering minimum nugget diameter)

Remarks: Very safe as per design requirement

Table 7: Details of peel test results

S. No	Weld Force X1 (Kgf)	Weld current X2 (Amps)	Weld time X3 (Sec)	Nugget diameter D (mm)
1	30	1800	0.1	2.7
2	45	1800	0.1	2.9
3	30	2484	0.1	2.8
4	45	2484	0.1	2.7
5	30	1800	0.3	3.2
6	45	1800	0.3	3.1
7	30	2484	0.3	3.0
8	45	2484	0.3	3.2

Table 8: External Observations of depth of indentation on top and bottom specimen

Trial	Depth of indentation	
	Top sheet (mm)	Bottom sheet (mm)
1	0.060	0.075
2	0.070	0.085
3	0.080	0.070
4	0.090	0.08
5	0.075	0.085
6	0.088	0.09
7	0.90	0.080
8	0.95	0.98

Table 9: Details of observation of spot diameter and HAZ for top and bottom specimens

Trial	HAZ (Top sheet - mm)	HAZ (Bottom sheet –mm)
1	47	4.2
2	4.4	4.5
3	4.2	3.8
4	4.3	3.9
5	5.3	4.6
6	4.8	4.4
7	5.4	4.90
8	4.7	4.4

Fig.3 10 KVA spot welding equipment used in trials

Fig.4 Tension shear test or breaking load test by using 40 Ton UTM

Fig.5 Specimen samples.

Fig.6 Specimen holding fixture for UTM

Fig.7 view of direct spot welding

Fig.8 View of Peel testing

V. Appendix - Calculations

8.10 - Calculations for the d/t ratio for the tested specimen

Design of weld with reference to Welding technology and design; author V.M. Radhakrishan, the ratio of d/t = 1.28 (yield stress / shear stress). The bending stress in the spot weld by considering the weld nugget features are d = diameter of the weld nugget and t = thickness of the weld nugget

Bending stress = p / d t

= shear stress (d2 / 1.28 d t)

= d / 1.28 t

Or d / t = 1.28 (Bending load / Shear load)

Thus ratio of (d / t) will be governed by the maximum permissible shear strength in the spot weld and yield strength of the base material, under the assumptions on yield stress = bending stress ,

Thus we have, **(d / t) = 1.28 (yield stress / shear stress)**

calculation of shear stress:

Cross section of the spot = π d $(spot)^2/4$

Shear stress = p / π d $(spot)^2/4$

= 4p / π d $(spot)^2$

= 1.28 (p) /d2

8.2 - Data considered for the discussions to evaluate the design value:

P= Tension shear load in kgf =220 kg,

t= thickness of the sheet = 0.8mm (specimen) , W= width of the sheet= 25mm (specimen),

Material = low carbon steel sheet and UTS of the material= 30 kg/mm², Shear strength= 15 kg/mm²,

Test conducted with electrode is of diameter 4mm so that spot diameter is 3 mm,

Let,

A= Area of spot = $\pi d^2/4 = \pi (2.7)^2/4 = 5.7$ mm², Shear stress of spot = 15 kg/mm²,

Tension shear load = shear stress× Area of the spot = 5.7 × 15 = 85.5 kg ,say 85 Kg

But as per the results gave tension shear value 220 kgf,

factor of safety = 220/85 = 2.5 (F.S.),

by considering the Factor of safety =2.5,

Therefore, for design value will be considered up to a maximum of 85 kgf, then

Observed value for the direct resistance spot welding = 400/85≈ 4.7

Base metal strength of the specimen

Area of the cross-section of the specimen= 25×0.8= 20 mm²,

Shear of the specimen = 15 kg/mm² and The failure load = 15× 20 =300 kgf

8.3- Detail calculations of d/t Ratio as per design requirement and experiment by Peel Test

8.3.1 As per design requirement.

we have (d / t) = 1.28 (yield stress) / shear stress

For maximum yield stress d/t = 1.28 x 21 / 15 = 0.9

8.3.2 As per peel test results

d /t , where d = Diameter of nugget in mm, t = thickness of the sheet in mm

Minimum diameter of the nugget = 2.7 ,

Maximum diameter of the nugget = 3.2

Thickness of the sheet = 0.8 mm , then ratio of d/t = 2.7/0.8 = 3.4 (By considering minimum nugget diameter)

8.4 - Discussions about theoretical tension shear load and experimental tension shear load

From base material of the specimen;

Area of the cross section = 25 X 0.8 = 20 mm2

Shear stress of the base material = 30 / 2 = 15 kg / mm2

Breaking load under shear = 15 X 20 = 300 kgf

Tension shear load for direct spot welding = 400 kgf

Ratio of Experimental tension shear to theoretical load for DSW = 400 / 300 = 0.75

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