International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 11, November-2014

Application of Response Surface Methodology for Tensile Strength of Multi-Spot Welded Cross Tension Specimen

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Abstract- **The effect of design parameters and process parameters on the tensile strength of two similar galvanized steel sheets are investigated through experiments using response surface methodology (RSM) .Design parameters are number of spots, specimen thickness and radial spot spacing. Process parameters are squeezing force, welding current, weld time. Similar sheets of galvanized steel are made by resistance spot welding at different processing conditions and these joint populations have been tested under defined loading conditions. Specially fabricated and designed fixture is used to load cross tension in the universal testing machine Regression analysis is done to obtain relationship between tensile strength and selected parameters. Confirmation tests have been conducted to check accuracy of regression model.**

Keywords-Number of spots, Radial spot spacing, Tensile strength,

I. INTRODUCTION

Resistance spot welding (RSW) is a process of joining metal components through the fusion of discrete spots at the interface of the work pieces. It is one of the most useful and practical methods for the manufacture of sheet metal assemblies. This process is common for welding sheets of aluminum, stainless steel, titanium alloys etc. A typical automobile consists of more than 5000 spots [1].This study gives relationship among process parameters and strength of spot weld. Galvanized sheets are spot welded at permissible level of parameters so as to visualize interfacial mode of failure after tensile shear test [2]. Author considered processing time as parameter. It was observed that shear strength of spot weld increases with increasing processing time [3].This study consists of application of Taguchi method to study effect of process parameters on strength of spot weld [4]. This study consists of relationship between pre-straining and tensile shear of spot weld [5].Lap shear specimen is used and its fatigue strength is obtained through experimentation .Effect of nugget diameter on fatigue strength of spot weld is studied [6]. Effect of fusion zone size on the shear strength is studied [7]. Experiments were planned on the basis of response surface methodology (RSM) [8]. Effect of process parameters on the shear strength of spot welded lap shear specimen had been obtained. Higher levels of parameters were considered [9]. Authors used software package LS-DYNA. Objective of this simulation was to find out fatigue strength of spot weld and compare it with results obtained by KS2 test. KS2 test was conducted for loading in different direction so as to find out effect of direction on the fatigue strength [10]. Objective of this FE model was to develop a mathematical model. Here, input parameters were varied according to matrix from design of experiments and strength of the spot weld was obtained [11].

Strength of spot weld defines the quality of integrated structure of automobile and improves the reliability of assembled sheets. Structural stability of multi spot welded structure depends upon number of spots, their locations and variable loads acting on it. So, investigation on the relations between the tensile strength of spot weld, spot spacing and number of spots is the key to solve problem in the design of multi-spot welded structure. The diameter of the spot weld nugget, d, is chosen based on an empirical formula

$$d \geq 4\sqrt{t} \quad (1)$$

Resistance spot welding (RSW) is a process of joining metal components through the fusion of discrete spots at the interface of the work pieces. However, several author claim that this equation is not safe for thickness beyond 1.5 mm.

Resistance spot welding joints are done on specimens of size 120 mm× 40 mm×0.27mm. Figure 1 shows the geometry and dimensions of the welded specimens. Sheet surfaces were randomly abraded with silicon carbide paper P220 grade. Specially designed and fabricated fixtures are used to load the cross tension specimen in universal testing machine.

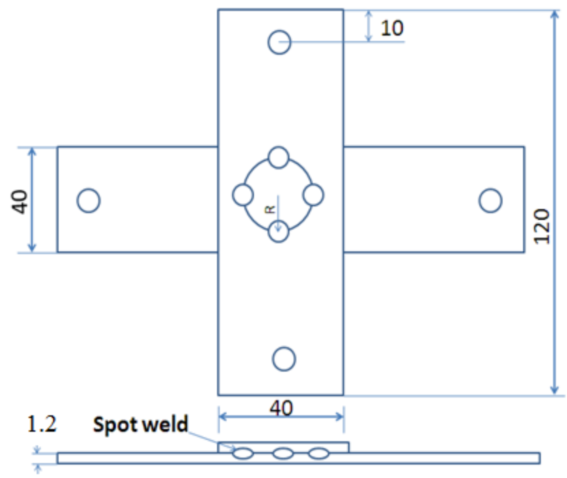

Fig.1 Dimensions of cross tension specimens (not to scale).

The welds were done using a RSW electric resistance spot welding machine, with a nominal welding power of 7.5 kVA.

II .EXPERIMENTAL PROCEDURE

The tensilestrength testing was done in a servo hydraulic Universal Testing machine at a cross-head speed of 1.31mm/min to 2 mm/min up to the final failure of the joint.Specimen failed Partially by pull out faiure mode under constantloading velocity.Selected ranges of parameters are given in table II as shown below. Electrode force is measured by using piston cylinder arrangement. Hydraulic pressure which is built up on piston head is transferred to upper surface of electrode. Pressure is calibrated to force by considering cross-sectional area of electrode. Nugget diameter is measured by using Brinell micro scope. It has been measured after testing of specimen. Part of works piece which is pulled out is measured as a nugget diameter. While some specimen failed in interfacial failure mode.

Table I .Chemical Composition of Galvanized steel sheet

T.S	Y.S	Alloying elements (wt. %)					
MPa							
		C	Mn	Si	S	P	Cr
350	240	0.16	0.3	0.25	0.03	0.03	0.004

Table II Ranges of Parameters

Sr.NO	Parameters	Low Level	High-level
1	Force (F)	2000	3000
2	Number of spots(n)	2	6
3	Radial Distance(R)	12	16
4	Thickness(t)	1.2	1.8
5	Current(I)	8000	9000
6	Weld Time(Cycle)	5	10

Fig.2 Photograph of Experimentation

Fixtures are designed for testing single and multi-spot welded cross tension specimen**.** It is explained as follows.A fixture should transmit the load symmetrically from the ram of universal testing machine to the joint of cross tension specimen. A fixture which should be strong enough to sustain the failure load of cross tension specimen.

Cross tension specimen of maximum thickness 2mm should be tested successfully.

Fixture should be capable to perform required number of test. A material stronger than that of mild steel is used to hang the fixture in the universal testing machine**.** Materials selected are cast iron and mild steel.Bolts and nuts of sizes M10 and M8 are capable of sustaining maximum load of 625N/mm^2 and 525N/mm^2. In order to add the strength in the plate, thickness of plate is kept 10 times more than that of thickness of specimen though they are made up of same material.

Table III Resistance Spot Welding parameters and corresponding Strength (Response Surface Methodology)

StdOrder	RunOrder	PtType	Blocks	I(A)	F(N)	T(cycle)	t(mm)	n	R(mm)	T.S(N)
27	1	1	1	8000	3000	5	1.8	6	16	2251.5
21	2	1	1	8000	2000	10	1.2	6	14	1955.1
18	3	1	1	9000	2000	5	1.2	6	14	2031.4
46	4	0	1	8500	2500	7.5	1.5	4	15	2127.2
49	5	0	1	8500	2500	7.5	1.5	4	15	2127.2
31	6	1	1	8000	3000	10	1.8	6	14	2265.6
42	7	-1	1	8500	2500	7.5	1.5	8	15	2170.1
43	8	-1	1	8500	2500	7.5	1.5	4	13	2137.0
8	9	1	1	9000	3000	10	1.2	2	16	2094.5
29	10	1	1	8000	2000	10	1.8	6	16	2157.3
20	11	1	1	9000	3000	5	1.2	6	16	2123.1
15	12	1	1	8000	3000	10	1.8	2	16	2222.9
45	13	0	1	8500	2500	7.5	1.5	4	15	2127.2
25	14	1	1	8000	2000	5	1.8	6	14	2159.8
12	15	1	1	9000	3000	5	1.8	2	16	2299.3
13	16	1	1	8000	2000	10	1.8	2	14	2131.2
11	17	1	1	8000	3000	5	1.8	2	14	2225.5
53	18	0	1	8500	2500	7.5	1.5	4	15	2127.2
33	19	-1	1	7310.79	2500	7.5	1.5	4	15	2029.5
41	20	-1	1	8500	2500	7.5	1.5	1	15	2101.4
10	21	1	1	9000	2000	5	1.8	2	14	2207.6
38	22	-1	1	8500	2500	12	1.5	4	15	2134.0
47	23	0	1	8500	2500	7.5	1.5	4	15	2127.2
24	24	1	1	9000	3000	10	1.2	6	14	2137.2
51	25	0	1	8500	2500	7.5	1.5	4	15	2127.2
23	26	1	1	8000	3000	10	1.2	6	16	2046.8
44	27	-1	1	8500	2500	7.5	1.5	4	17	2117.3
9	28	1	1	8000	2000	5	1.8	2	16	2117.2
14	29	1	1	9000	2000	10	1.8	2	16	2205.0
40	30	-1	1	8500	2500	7.5	2.21352	4	15	2377.5
19	31	1	1	8000	3000	5	1.2	6	14	2049.3
39	32	-1	1	8500	2500	7.5	0.78648	4	15	1876.8
48	33	0	1	8500	2500	7.5	1.5	4	15	2127.2
36	34	-1	1	8500	3689.21	7.5	1.5	4	15	2246.1
30	35	1	1	9000	2000	10	1.8	6	14	2247.7
32	36	1	1	9000	3000	10	1.8	6	16	2339.4
3	37	1	1	8000	3000	5	1.2	2	16	2006.7
5	38	1	1	8000	2000	10	1.2	2	16	1912.4
35	39	-1	1	8500	1310.79	7.5	1.5	4	15	2008.3
6	40	1	1	9000	2000	10	1.2	2	14	2002.8
4	41	1	1	9000	3000	5	1.2	2	14	2097.0
28	42	1	1	9000	3000	5	1.8	6	14	2341.9
7	43	1	1	8000	3000	10	1.2	2	14	2020.7
22	44	1	1	9000	2000	10	1.2	6	16	2028.9
17	45	1	1	8000	2000	5	1.2	6	16	1941.0
50	46	0	1	8500	2500	7.5	1.5	4	15	2127.2
1	47	1	1	8000	2000	5	1.2	2	14	1914.9
16	48	1	1	9000	3000	10	1.8	2	14	2313.3
26	49	1	1	9000	2000	5	1.8	6	16	2233.6
2	50	1	1	9000	2000	5	1.2	2	16	1988.8
34	51	-1	1	9500	2500	7.5	1.5	4	15	2224.8
52	52	0	1	8500	2500	7.5	1.5	4	15	2127.2
37	53	-1	1	8500	2500	5	1.5	4	15	2120.3

By using Microsoft excel-2007, Regression modeling has been obtained and it is given as follows.

The regression equation is

T.S= 674 + 0.0821 I + 0.100 F+ 1.15 T + 351 t + 8.23 n - 4.14 R… (2)

Where,

P=Tensile Strength in N, I=Current in Amp. t=Thickness in mm, R=Radial spot spacing. in mm n= Number of spots, f=Electrode force in N.

III.RESULT DISCUSSION

Spot welding current:-It is observed that there is significant increase in tensile strength of spot weld when spot welding current increases. It happens because increases in current increases heat generation and more amount of sheet surface melts thereby increasing size of heat affected zone and these results in decreases in grain size

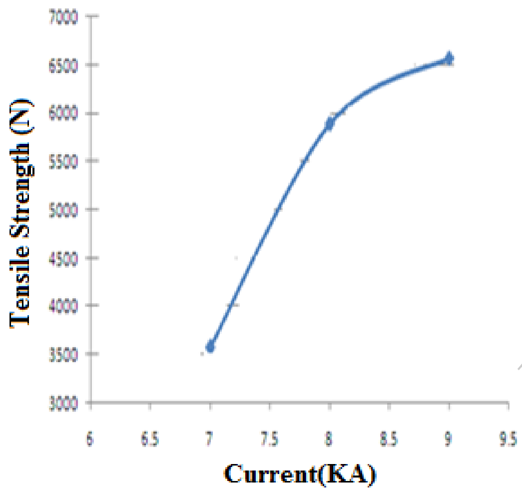

Fig.3 Relationship between current and tensile strength

Fig.3 shows relationship between spot welding current and tensile strength of spot weld. Spot welds made at 9 KA current got the strength 7689.906N.Spot welds made at 7KA got the strength 3507.19 N. It is observed that there is significant increase in tensile strength of spot weld when specimen thickness increases. Because increases in specimen thickness increases cross section area of specimen and tensile force acts parallel to cross section area. Fig.4 shows relationship between Specimen thickness and tensile strength of spot weld.

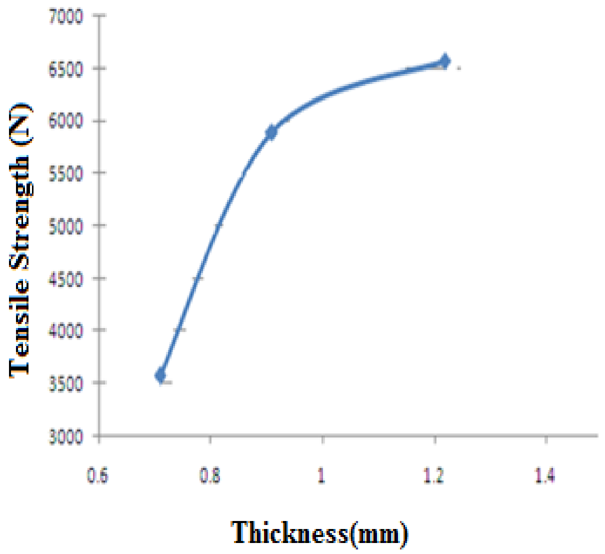

Fig.4 Relationship between specimen thickness and tensile strength

Spot welds made 1.22 mm thickness got the strength 7589.99N. It is observed that compromising with number of spots and increasing specimen thickness tensile strength can be improved. Spot welds made 1.22mm thickness but having lower value of current and number of spot, got the strength 3507.99N.

From the results of experimentations and regression analysis, effect of number of spot, spot spacing electrode force, weld current and specimen thickness on the tensile strength of spot welded cross tension specimen is obtained. By using the obtained equation from regression analysis, equation. (2), data is fitted on line. Effect of individual parameter on the tensile strength of multi spot welded cross tension specimen is obtained by keeping other parameters constant. It is discussed as below.

All spots failed at once due to axially applied load. Because applied load was equally distributed over generated spots .It is uniformly distributed over sheet surface. It is observed that there is significant increase in tensile strength of spot weld when number of spot increase .Fig.5 shows relationship between number of spot and tensile strength of spot weld. Specimens having six numbers of spot got the strength 5002.63N.Specimens having two numbers of spot got the strength 3001.32N. Here, tensile strength is increased because all spot welds were made up to 16 mm spot spacing .above this value of spot spacing, there is overlapping of heat affected zone

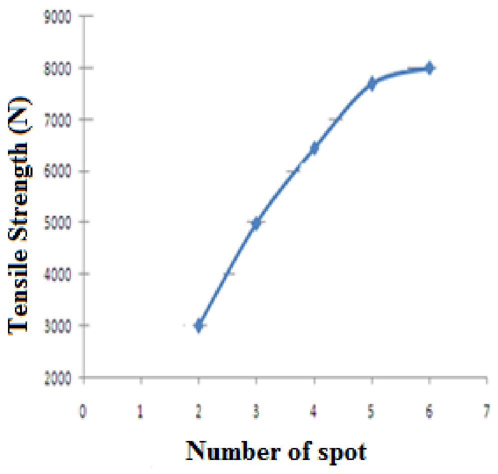

Fig.5.Relationship between number of spots and tensile strength

It is observed that there is significant decrease in tensile strength of spot weld when radial distance from specimen center increases. Fig.7 shows contour plot of tensile strength, number of spots and radial distance of spot from specimen center. It can be seen that maximum tensile strength 131.421.Kgf can be obtained at radial distance 8 mm and 6 numbers of spot.These values of radial distance and number of spots can be said as optimum values. Specimens which are having number of spot 2 , 3 and 4 at the radial distance varying from 8 to 10 .5 mm got the tensile strength less than 20 Kgf. It is observed that there is necessity to increase number of spot along with radial distance in order to obtain sufficient tensile strength.

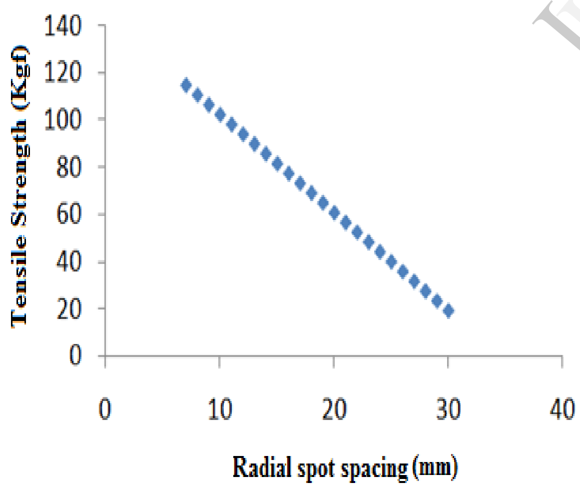

Fig. 6 Relationship between tensile strength of spot weld and radial spot spacing.

According to the results of experimentations and regression analysis, effect of radial distance of spot from specimen center (radial spot spacing) on the tensile strength of spot welded cross tension specimen is obtained. Electrode force, weld current and specimen thickness, number of spot have same effect on the tensile strength as that of shear strength. By using the obtained equation from regression analysis, equation. [2], data is fitted on line and plots are drawn according to the design matrix RSM. Effect of individual parameter on the tensile strength of multi spot welded cross tension specimen is obtained by keeping other parameters constant

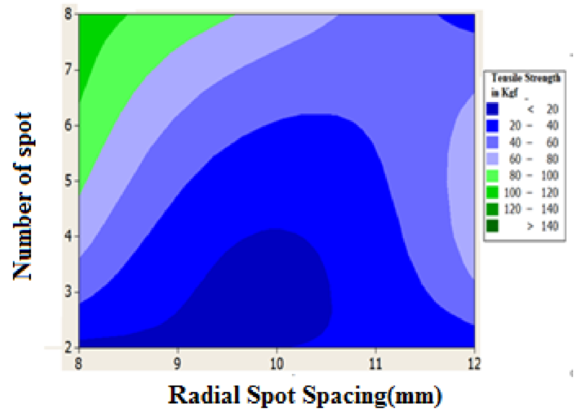

Fig.7 .Relationship among tensile strength of spot weld, number of spot and radial spot spacing

Obtained equation of regression is validated through confirmation tests. By comparing results of regression equation and experimental result, it can be seen that there is 0.85 % maximum deviation between experimental results and results obtained by regression equation. So, obtained equation is good in agreement.

Table IV Confirmation test of regression model for cross tension specimen

IV.CONCLUSIONS

Sr. No	Tensile strength (Kgf)		%Deviation
	Regression Model	Experimentation	
1	350.3867	349.458	0.265043
2	354.8318	351.7893	0.857441
3	359.2769	358.3746	0.251136
4	363.722	361.6738	0.563115

a) Fixtures are designed and fabricated so as to load the specimen in universal testing machine. Simple regression equations have been proposed to predict the static tensile shear strength of single spot and multi spot welded lap shear specimen. Obtained equations are validated by conducting confirmation tests. A significant increase in the failure load in static shear lap tests is observed in welds done. With increasing time, the failure changes from interfacial mode to pullout mode. Increase in electrode force causes increase in tensile strength and considerable bending of specimen occurs in pullout failure mode. The effect of number of spots on the shear strength of spot weld has been analyzed.

b) It is observed that maximum tensile strength 131.421.Kgf is obtained at optimum values, radial distance 8 mm and optimum 6 numbers of spot.

c) Confirmation tests for suggested regression model of tensile strength of cross tension multi spot welded specimen show that there is maximum 0.857441 % deviation between experimental results and results obtained by regression equation.

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