OPTIMIZATION OF RESISTANCE SPOT WELDING FOR MULTI SPOT WELDED CROSS TENSION SPECIMEN

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Abstract : In this paper parametric analysis of multi spot welded cross tension specimen is carried out to investigate the effect of design and process parameters on the tensile strength of spot welded specimen. Further, study is carried out to develop mathematical model by using regression analysis. The design parameters considered are specimen thickness, number of spots and radial spot spacing whereas process parameters are welding force and welding current. As per Taguchi design of experiment approach, five welding parameters with three levels of each are considered for analysis. Experimentation is carried out as per L_{27} orthogonal array to investigate the effect of welding parameters on tensile strength. Optimum welding parameters are determined by particle swarm optimization (PSO) method. Tests for confirmation have been conducted to validate the results. From the analysis it is observed that maximum tensile strength 2275.49 N is obtained at optimum values, radial distance 8 mm and optimum 6 numbers of spot.

***Index Terms* - Number of spots, Radial spot spacing, Particle swarm optimization, Tensile strength.**

I. INTRODUCTION

Resistance spot welding (RSW) is a conventional welding technique to join thin metal sheets by the heat generated at the joint due to the contact resistance to the flow of electric current, where nugget is not visible outside. The joining of sheet metal is a combination of a mechanical, electrical, thermal and metallurgical phenomenon. It is different from other welding processes, as the filler material is not required. It has astounding techno-monetary advantages, for example, ease, high creation rate and flexibility for mechanization which settles on it an appealing decision for auto-body gatherings, truck lodges, rail vehicles, and home machines. The transport sector is having tremendous application of spot welded joint [1]. This process is regular for welding sheets of various metals like steels, titanium, aluminium alloys, and so on. It is a sophisticated amongst the most prepared of the electric welding forms being used by industry today. Interfacial mode of failure was observed after tensile shear test of spot welded galvanized sheets at the permissible level of parameters [2]. Impact of design and process parameters on the tensile strength of galvanized steel sheets are examined through investigations. This examination comprises of utilization of the Taguchi strategy to think about the impact of process parameters on the quality of spot weld [3]. The quality of spot weld characterizes structural stability of the automobile and improves unwavering quality of assembled sheets [4]. The author found that the shear strength of spot welds increases with increments in processing time [5]. The fatigue strength of the lap shear specimen is prepared and the importance of nugget diameter spot weld is evaluated [6]. Examine the improvement and impact of welding parameters on the spot welded AISI 301L stainless steel. The level of significance of the welding parameters is controlled by ANOVA [7]. Spot welding of greased up sheet brings about a more uniform and diminished alloyed material take-up that stores on the welding anode cap [8]. Examine the part of the zinc layer in RSW of aluminum to steel through correlation of microstructures and mechanical properties of the resistance spot welds amongst aluminum and low carbon steels [9] [10]. In spite of the fact that this work author establishes a mathematical model by changing welding input parameters as indicted by matrix from design of experiments and strength of the spot weld was acquired [11]. The Taguchi technique, a prominent experimental design method used in the industry, can mitigate the limitations of full factorial design and methodologies the optimization of parameter design, although the number of experiments is reduced [14]. Possibility of producing even one or two defective welds needs to be eliminated, in order to ensure and maintain structural integrity under a wide range of operating conditions of finished component. Now a day, weld manufacturer's practice for more spot welds than what actually needed for maintaining structural integrity. As the cost associated with overwelding is significant provides a considerable driving force for optimization of resistance spot welds.

Till date several attempts have been made by many researchers to model the spot welding process, investigating the influence of the spot welding parameters on resistance spot weld performance and identifying the optimal welding parameter. However, the resistance spot welding is non-linear process requires the application of deterministic as well as stochastic techniques. The number of spots, their locations and loads acting on welded structure ensure the stability of structure. So, investigation on the relations between the strength of multi-spot weld and design parameters is the key to solve the problem in the design of the multi-spot welded structure. Therefore, the optimization of the resistance spot welding process will remain a key research area, matching the numerous welding parameters with the performance measures of resistance spot welds. This work will help to set the optimum welding parameters for multi- spot welded lap shear specimen to achieve the maximum tensile shear strength. Based on an empirical formula recommended by the American Welding Society (AWS), the diameter of the spot weld nugget, d, is chosen and considered as follows

$$\mathbf{d \geq 4*t} \qquad (1)$$

1.1 Heat Generation in Resistance Spot Welding

To ensure a good quality weld, the weld current, weld time and contact resistance, must be controlled properly. The amount of heat generated is governed by:

$$\mathbf{Q = I^2RT} \qquad (2)$$

Where,

Q - Heat generated, J; I - Welding current, A; R - Resistance of the work piece, Ω and T - Time of current flow, Sec or cycle.

1.2 Resistance Spot Welding Parameters

Theoretical study related to parameters of spot weld is carried out. Impact of welding parameters on the tensile strength can be seen on developed cause effect diagram is shown in Fig.1.

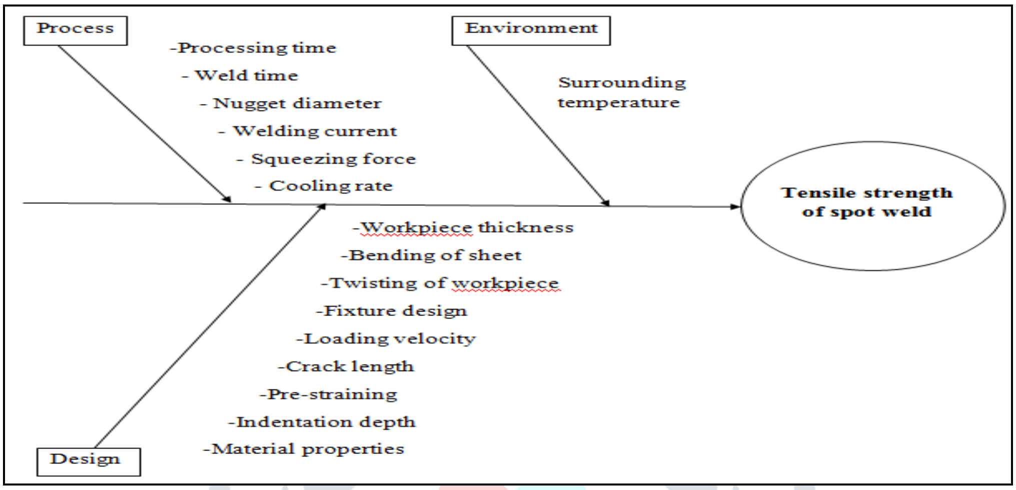


Fig.1 Cause-effect diagram [12]

II. DESIGN OF EXPERIMENT

2.1 Selection of Welding Parameters and Levels

In the present investigation of resistance spot welding, five fundamental parameters particularly welding current, welding force, specimen thickness, number of spots, spot spacing are chosen with three levels of each as shown in Table 1. The output parameter foreseeing quality of weld joint is tensile strength.

Table1: Parameters and Level

Parameters	Level			Notation
	1	2	3	
Welding Current (KA)	8959	9104	9554	A
Specimen Thickness (mm)	0.19	0.27	0.3	B
Welding Force (N)	350	425	497	C
Radial Spot Spacing (mm)	8	10	12	D
Number of Spots	2	4	6	E

2.2 Design of Experiment

Analysis of manufacturing and production processes has been done by using design of experiments and taguchi method. The statistical experimental design method can be used to improve the quality. This is form of design of experiment (DoE) with special application standards. It helps to investigate the impact of different welding parameters on welding quality at various level and optimal settings of the various parameters have been practiced by utilizing Taguchi examination. Here for experimentation we select L_{27} Taguchi orthogonal array (OA) for five welding parameters and three levels of each parameters.

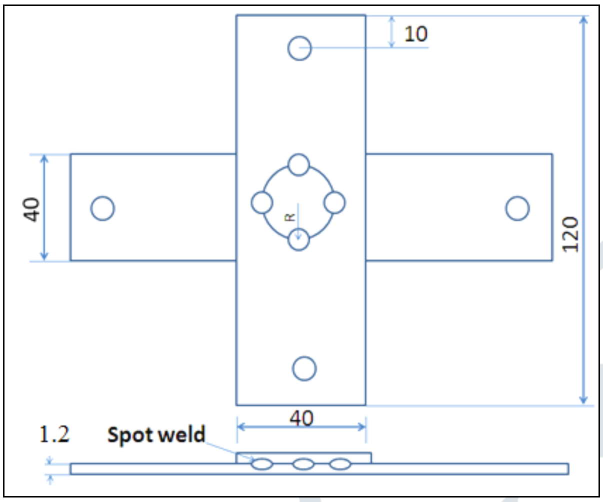
III. EXPERIMENTATION

3.1 Specimen Preparation

The test specimens were cut from galvanized steel sheet metal of size 4ft × 4ft. The measured dimensions for test specimen are 120 mm length (L) and 40 mm width (W) with an overlap of 40 mm. The material used in the present work is a galvanized steel sheet of 1.22 mm thickness (T). Sheet surfaces were randomly rubbed by using silicon carbide paper P220 grade. The welds were made by utilizing an electric resistance spot welding machine, having 10 KVA as nominal welding power. The chemical composition for of test specimen is listed below in Table.2. Test specimen design and its FE model shown in Fig.2.

Table. 2
Chemical composition of Galvanized steel sheet

T.S	Y.S	Alloying elements (wt %)					
MPa		C	Mn	Si	S	P	Cr
350	240	0.16	0.30	0.25	0.030	0.03	0.004



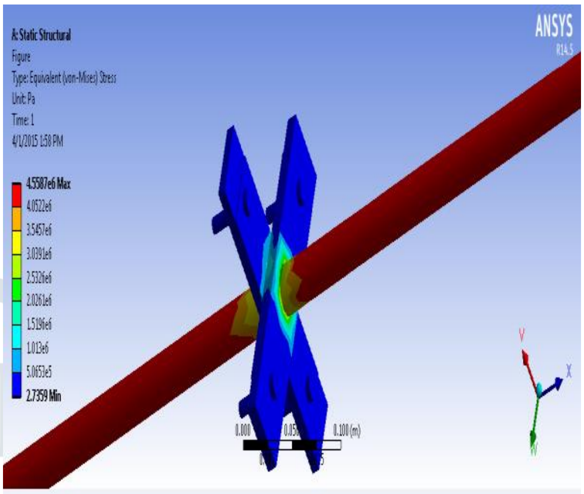
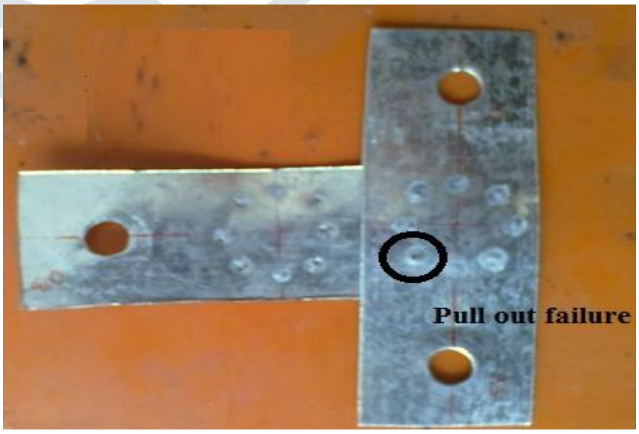


Fig. 2. a) Work piece design for test specimen b) Stress analysis of fixture with specimen in ANSYS.

3.2 Experimental Procedure

The tensile strength testing was done by utilizing 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. For selected ranges of parameters, partial pull out failure was observed for the test specimen under constant loading velocity. The Brinell microscope is utilized to measure the diameter of nugget. It has been measured after testing of the specimen. Specially designed and fabricated fixtures are used to load the cross tension specimen in the universal testing machine. The fixture is designed and manufactured such that it should transmit the load symmetrically to the joint of the test specimen from the ram of testing machine, strong enough to sustain the failure load of the test specimen and must perform the required number of test. A material stronger than that of mild steel is used to load 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/mm2 and 525N/mm2 shown in as shown in Fig.3. Cross tension specimen of maximum thickness 1.22mm should be tested successfully.

(a)



(b)

Fig. 3. Testing of multi spot welded cross tension specimen

Tensile testing has been completed at dynamical loading condition for example; loading velocities are 1.32m/min and 2 m/min. At different loading velocity, the dynamic strength was measured. Ten number of test specimens are tested. Sample load verses displacement curve is shown in Fig.4 (a).

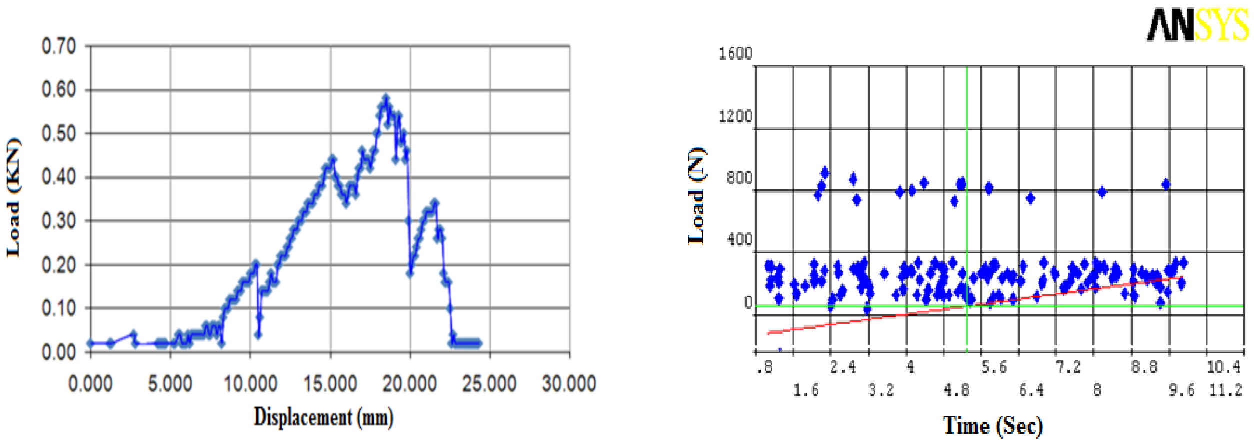


Fig.4. (a) Load verses displacement curve (b) Load verses time

Loading velocity was constant up to 5mm displacement. It was observed that load was increased linearly with increase in time. Spot welded test specimens have been made by keeping same welding conditions and tested at different loading velocities. The results of the dynamic strength tests are shown in Fig.4. (a)

Same configuration of specimen has been modeled in FEM package ANSYS and loading has been done in different intervals of time. Thirty numbers of simulations are run and range of loading time has been kept in between 1 to 11 second. Fig.4. (b) shows loading conditions of spot welded specimen with respect to time.

IV. TAGUCHI ANALYSIS

4.1 Signal to Noise Ratio

Analyzing the data using the S/N ratio helps to select the optimum level based on least variation around on the average value, which closest to target. Furthermore, compare two sets of experimental data with respect to deviation of the average from the target. The experimental results are analyzed to explore the main effects. According to quality designing, the characteristics are classified as Higher the best (HB), lower the best (LB) and Nominal the best. HB includes Tensile strength which desires higher values. As the experimental design is orthogonal, the impact of each welding process parameter on the S/N ratio at different levels can be obtained separately. For each level of the welding parameters and process output, the S/N ratio was summarized. By using Minitab software, the mean, S/N ratio for each level of the welding parameters is summarized and tabulated values are shown in Table.3. For each welding parameters corresponding higher tensile strength, which parameter level is significant shown in Fig. 5. The optimal combination which gives higher tensile strength is A2B3C1D2E3.

Table 5: Response for Signal to Noise Ratios

Level	Current (KA)	Thickness (mm)	Electrode Force (N)	Radial Spot Spacing(mm)	Number of Spots
1	26.00	31.56	34.96	32.08	30.71
2	37.36	33.74	31.80	34.57	34.79
3	37.24	35.31	33.86	33.96	35.11
Delta	11.36	3.75	3.16	2.49	4.40
Rank	**1**	**3**	**4**	**5**	**2**

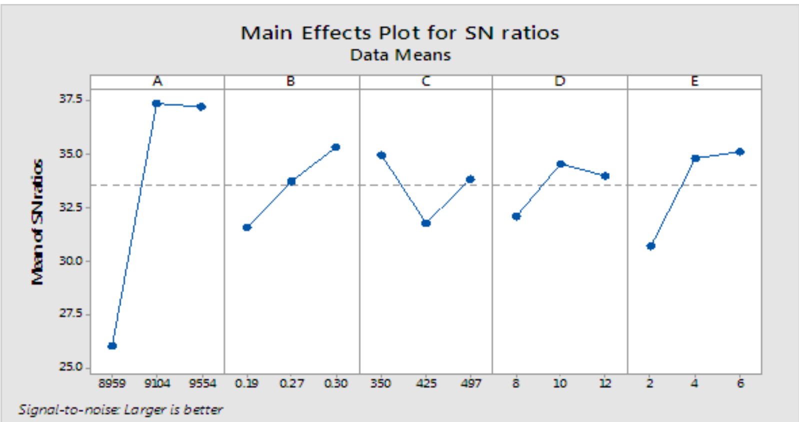


Fig.5. Main effects plot for S/N ratio

4.2 Analysis of Variance

The use of the analysis of variance (ANOVA) is to find out the welding process parameters, which can prodiminetly, affect the quality attributes [14]. The percent contribution in the total sum of the squared deviations can be utilized to assess the significance of the welding process parameter change on these quality attributes. Decomposition of variance is done to get the impact of the different welding parameters on the tensile strength (T-S). ANOVA is used to found out the design parameters in order to show the parameters which are significantly influencing the output parameters. The sum of squares and variance are also calculated during the analysis. To choose the significant factors affecting the process, F-test value at 95 % confidence level is used and percentage contribution is calculated. The variation of the process parameter shows an improvement on the performance indicated by the larger F-value. The ANOVA analysis for tensile strength is shown in Table 4.

Table 4: Results of ANOVA for Tensile Strength

Source	DF	Adj. ss.	Adjss. MS	F-Value	P-Value
A	2	24702.5	12351.3	21.83	0.001
B	2	4504.9	2252.4	3.98	0.063
C	2	2914.3	1457.1	2.58	0.137
D	2	2908.6	1454.3	2.57	0.137
E	2	7959.7	3979.8	7.03	0.017
A*D	4	879.6	219.9	0.39	0.811
A*E	4	11654.0	2913.5	5.15	0.024
Error	8	4526.5	565.8	-	-
Total	26	60050.2	-	-	-
S = 23.7869, R-sq =92.46%, R-sq (adj) = 75.50%					

According to Table 4, Welding current was observed to be the significant factor influencing the tensile strength, number of spots was observed to be the second-positioning component, while thickness, electrode force, and radial spot spacing have ranking sequentially.

V. REGRESSION MODELING

Data obtained from experimentation has been analyzed by performing a regression analysis. Regression models are developed for tensile strength of cross tension specimen with the multi-spot. Randomly spot welded cross tension specimens are tested for tensile strength. The regression equation has been obtained, and it is given as follows.

Tensile Strength =34060- 4.50 Current- 99432 Thickness+ 58.3 Electrode Force- 899 Radial Spot Spacing- 5164 Number of spot
+ 15.75 Current*Thickness - 0.00404 Current*Electrode F+ 0.048 Current*Radial Spot Spacing
+ 0.496 Current*Number of spot - 103.1 Thickness *Electrode Force- 233 Thickness *Radial Spot Spacing
+ 596 Thickness*Number of spot + 0.752 Electrode Force*Radial Spot Spacing
- 0.088 Electrode Force*Number of spot + 61.4 Radial Spot Spacing*Number of spot **(3)**

The obtained regression equation is validated by confirmation tests. A comparative result by the regression equation and experimentation in Table.5 shows that there is a 0.85 % maximum deviation. So, the obtained equation is right in agreement.

Table.5: Comparative results for Tensile strength

Sr. No	Tensile strength (N)		Percentage Deviation [(X1-X2)/X1]×100
	X1 Regression Model	X2 Experimentation	
1	3436.12	3427.01	0.265124
2	3479.71	3449.87	**0.857542**
3	3523.30	3514.45	0.251184
4	3566.89	3546.81	0.562955

VI. SIMULATION

Cross tension three spot welded specimens are modeled for simulation. In order to perform simulation FEM package ANSYS is used. Solid 186, MPC 184, Target 170 and Contact 175 are the elements selected for meshing the geometry of the test specimen. In order to define spot weld MPC184 element is used. Material properties are entered. Mapped type mesh geometry is done by giving element size 5mm and meshed model of specimen is shown below in Fig.6. Same configuration of specimen has been modeled in FEM package ANSYS and loading has been done in different intervals of time. Time has been kept in between 1 second to 11 second. Fig.7. shows load verses displacement curves which are obtained by experiment and finite element method.

Both curves are obtained at loading velocity 1.32 m/min and 2m/min. As far experimental results are considered, Strength increases by 1.318% as loading velocity increases from 1.32 to 2m/min. In finite element analysis, it is observed that strength increases by 1.597% as loading velocity varies from 1.32m/min to 2m/min. There is maximum deviation of 3.80 % by comparing strength values obtained through experimentation with strength values obtained through FEM at loading velocity 2m/min.

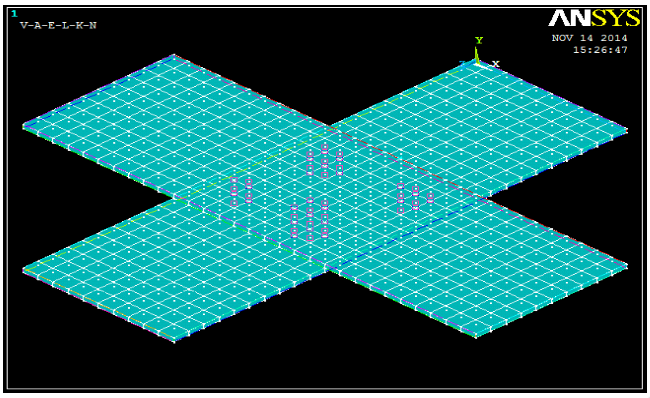


Fig.6. Meshed geometry of four spot welded specimen

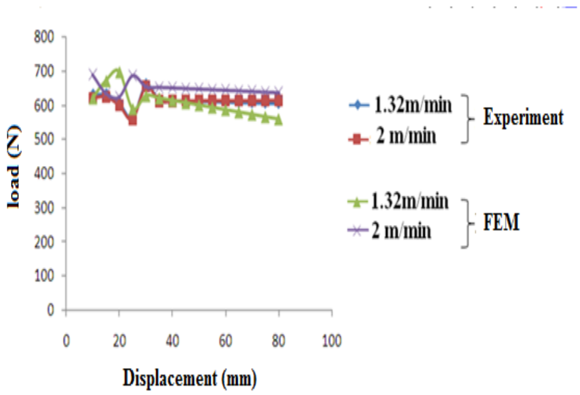


Fig.7. Load verses displacement

During the simulation, input variables displacement; spot weld radius; thickness and time of analysis are varied shown in table.6

Table 6: Random Input Variable Specifications multi spot welded cross tension specimen

No.	Name	Type	Par1	Par2
1	DISP	UNIF	0.10000	0.90000
2	R	UNIF	1.0000	5.0000
3	T	UNIF	0.71000	1.5000

DISP, R, T represents displacement of one end of specimen, spot weld radius and thickness respectively. During simulation, response parameter is selected as maximum shear stress at spot welding element. Non-linear properties of material are entered. At one end of specimen all degrees of freedom (DF) are made zero while displacement is subjected to other end. Suitable range of displacement is selected to avoid excessive distortion of the elements. Each progression is incremented by 1. Then, simulation loop is defined. It is executed multiple times within defined range by varying design parameters randomly.

VII. OPTIMIZATION

In the field of computational intelligence, Particle swarm optimization is an intelligence optimization algorithm and is utilized to improve the performance of the process. In this algorithm, each particle indicates a potential solution to the optimization problem and related to a value which may be determined by the fitness function. Each particle's velocity decides the moving direction and separation following its and other particles' movement to complete the dynamic change. At that point improvement in the arrangement space is accomplished. For every cycle, the particles update their speed and position by considering the fitness value, personal optimal solution, and the optimal global solution. In this paper, we utilize the PSO to optimize the penalty parameter, C. We set the iteration number to 500, and the size of the population is set to 25 in the PSO. Then we introduce the mutation into the PSO algorithm to avoid the problems of premature convergence and low iteration efficiency in later periods which can expand the search space to ensure population diversity and improve the ability to search the optimal solution. Particle swarm optimization for tensile shear strength is shown in Table.7.

Table 7: Optimization result for Tensile strength

Particle	10	25	50	75	100	200	300	400	500
A	9510.361	9522.82	9525.136	9554	9554	9543.132	9547.826	9554	9554
B	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
C	358.3869	369.4536	407.4324	350	350	360.2529	358.5343	350	350
D	12	12	12	12	12	12	12	12	12
E	6	6	6	6	6	6	6	6	6
Tensile Strength	**2150.852**	**2151.077**	**2057.112**	**2275.493**	**2275.493**	**2222.243**	**2237.801**	**2275.493**	**2275.493**

VIII. RESULTS AND DISCUSSION

From the experimental, regression and simulation results, effect of selected welding parameters on the tensile strength of cross tension specimen is obtained. Effect of each welding parameter on the tensile strength of multi spot welded cross tension specimen is obtained by keeping other parameters as constant. It is discussed as below.

It is observed that there is significant increase in tensile strength of spot weld when number of spot increase.Fig.8 shows relationship between number of spot and tensile strength of spot weld. Specimens having six number of spot but made at lower values of other parameters, got the strength in between the range 1850N-2375N.Spot welds made at lower level are failed in interfacial failure mode while spot welds made at higher level are failed at pullout failure mode. All spots were failed at once due to axially applied load and it is uniformly distributed over sheet surface.

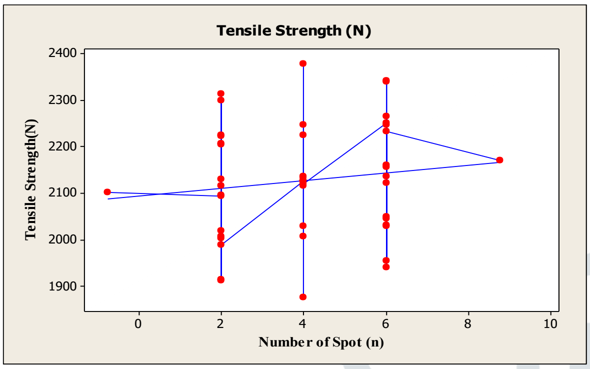


Fig.8 Tensile Strength Vs. Number of Spot

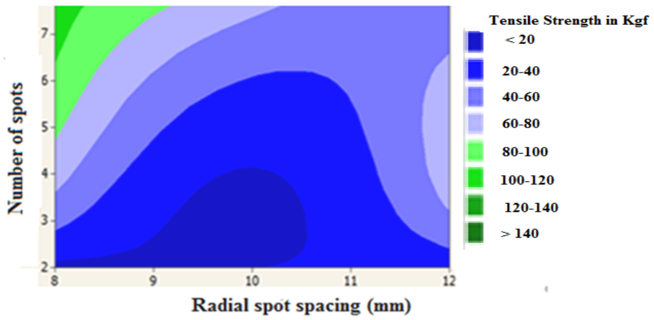


Fig.9. Contour plot of tensile strength, number of spots and radial spot spacing

Figure 9 shows contour plot of tensile strength, number of spots and radial spot spacing. Specimens which are having number of spot 2 and 6 (optimum number of spots) at the same time, specimens having radial spot spacing 8 mm to 12mm failed in the blue colored region. It can be said as optimum range for spot spacing .It is observed that spot welds made at electrode force 1961.3 N fail in pull out failure mode and remaining welds fail in interfacial failure mode. It is observed that there is necessity to increase number of spot along with radial distance in order to obtain sufficient tensile strength.

The curve in Fig.10 show that the shear stress remains below 523.703 N/mm^2 with a 90% probability. It shows that, within the selected ranges of input parameters multi spot welded specimen will not fail.

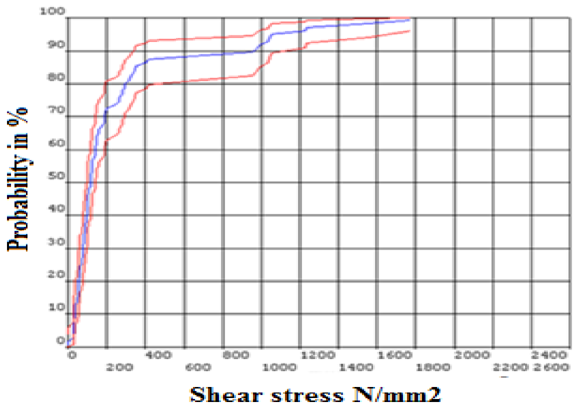


Fig.10. Shear strength Vs Probability

Table.8 shows results validation for tensile strength of multi spot welded specimen by experimentation and simulation etc.

Table 8: Results validation for tensile strength of multi spot welded specimen

Number of Spots	Tensile Strength in N		
	Experimentation	Regression Model	Simulation
1	1294.2	1246.2	1411.3
2	2117.9	2179.1	2231.4
3	2983.6	2703.3	2911.1
4	3116.7	3136.9	3275.6
5	3245.9	3382.3	3397.5
6	3566.8	3687.8	3669.7

Table.9 shows the results of experimental confirmation and comparison of the predicted and actual tensile strength for the optimal welding parameters. The improvement in tensile strength from the initial welding parameters to the optimal welding parameters is 2275.49 N for 1.2 mm galvanized steel sheets. In this way, the tensile strength is significantly improved by using the particle swarm optimization method.

Table 9: Results of the Confirmation Experiment

Factors	Initial combination	Optimal Combination		Maximum Tensile Strength (N) by PSO
		Prediction	Experimentation	
Operating Setting	A1B1C1D1E1	A2B3C1D2E3	A2B3C1D2E3	
S/N Ratio	42.2692	61.6922	61.47	67.14
T-S Strength (N)	234.8	1215.1	1185	**2275.492889**

Fig. 11 Tested cross tension specimen

Figure 11 shows photograph of Cross tension specimen tested in universal testing machine prepared as per L_{27} array.

IX. CONCLUSION

To predict the tensile strength of multi-spot welded cross tension specimen regression analysis is done to propose simple regression equations. Obtained regression equation is approved by conducting confirmation tests. The confirmation tests showed that it is conceivable to improve the tensile strength significantly. From the analysis it is observed that maximum tensile shear strength 2275.49 N is obtained at optimum values, radial spot spacing 08 mm and optimum 06 numbers of spot for 1.22 mm galvanized steel sheets by particle swarm optimization.

1. Confirmation tests for the recommended regression model for tensile shear strength of cross tension multi-spot welded specimen show that there is maximum 0.85744 % deviation between experimental results and results obtained by regression equation.
2. There is 3.80% maximum deviation in between results of experimentation and simulation at loading velocity 2 m/min, for tensile strength of multi spot welded cross tension specimen.
3. Results of simulation show that there is a about a 90% probability that the shear stress remains below 523.703 N/mm^2. It indicates that multi spot welded specimen will not fail within the selected ranges of input parameters
4. It is observed that maximum tensile strength **2275.49** N is obtained at optimum values, radial distance 8 mm and optimum 6 numbers of spot.
5. Tensile strength increases as the loading velocity increase from 1.32m/min to 2m/min.

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