Optimization of Spot Welding Processes in Low Carbon Hot Rolled Sheets

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Abstract. Spot Welding is an important process of permanently joining different metal parts and widely employed in modern manufacturing and aerospace industry. Different spot welding parameters namely hold time, ramp time, weld current and electrode force are used to optimize welding quality. Increasing the weld current improves the weld shear strength and reduces inconsistency of the welding quality. Optimization of the results based on the relationship between current and tensile load through experimental optimization and microstructure analysis in Resistance Spot Welding (RSW) indicate strong relationship in attaining good weld quality. The optimization of spot welding parameters is the most important task required to obtain welded sheet with high safety and quality standards for trailer bodies and trucks

1. Introduction

1.1 Introduction to Optimization and Spot Welding

The experimental optimization of a welding process is often a very costly and time consuming task due to many non-linear events involved. Number of processes recorded in the literature used for optimization of weld parameters [1] are hold time, squeeze time, weld time, electrode force and weld current density. One of the most widely used methods to solve this problem is Genetic Algorithm (GA) in which global results are obtained with high chances of probability [2]. Response Surface Methodology (RSM) is another method in which solution of problem is obtained through approximating the unknown with and appropriate empirical model. Identifying and fitting a good response surface model from experimental data requires some knowledge of statistical experimental design fundamentals, regression modeling techniques and elementary optimization methods [3].

1.2 Literature Survey

Resistance of the weld joints to the high electrical current is passed at the contact surfaces, causes localized heating resulting in a spot weld through application of pressure at electrodes. The amount of heat generated is a function of current, time and resistance between electrodes and given by expressions:-

$$H = I^2RT \text{----------------} \quad (1)$$

Where H= Heat generated in joules, I = current, R = Resistance T= time

$$E = 0.241\, I^2\, Rt_{\mathrm{w}} \text{----------------} (2)$$

$$\mathrm{E}= J_v S L \text{----------------} (3)$$

J_{v} : Melting energy (J/mm^{3})
S : Surface contact (mm^{3})
L: Total Plate thickness (mm)

$$I = \sqrt[2]{\frac{J_v[\pi 4 t \min\ ]L}{0.241\, Rt_{\mathrm{w}}}} \quad \text{----------------} (4)$$

$$= J_v[\pi \frac{dx}{4}]L \text{----------------} (5)$$

Where d : Required nugget diameter (mm)
Since $d = \sqrt[4]{t\, min}$ for general spot point
$= \sqrt[5]{t\, min}$ for Important spot point
$tmin$: Min thickness of panel combinations

Important welding parameters hold time, weld time, ramp time, diameter of the electrode surface and weld current optimize weld quality. Increasing hold time, weld time and electrode force improves weld strength reducing inconsistency of the welding quality [4]. Molybdenum (Mo) alloyed with Rhenium (Re) increases strength and creep resistance for sheets pre-joined through RSW in refractory alloys [5].Optimization of the results based on the relationship between weld force with current indicate strong relationship when most weld heads are properly calibrated [6].

2. Methodology

2.1 Experimental Details

In the current design of experiment, samples of low carbon steel composition as C 0.03%, Ni 0.03%, Mn0.1% P 0.011%, Cr 0.03%, Al 0.07%, Cu 0.04% and base Fe were chosen. Used in manufacturing of steel body of a mobile field vehicle, were subjected to severe field transportation condition. In the traditional process, metal sheets were joined by spot welding resulted in a fusion zone between the referred joining metal sheets with strength of the spot weld measured through diameter of the nugget [7].

The broad parameters of welding process were finalized to attain maximum output of the assigned work and an approach based on determining tensile loads and micro structure analysis for optimized parameters for ideal spot welding process was adopted. Low carbon hot rolled sheets samples were prepared through spot welding. The test samples were 200 mm in length and 40 mm in width with an over lap of 40 mm. A stationary spot welding machine with rated capacity of 85 KVA and electrode force of 0.5 Mpa was used. In the experimental set up, tensile loads were determined through universal testing machine. The results were recorded through Sintech UTS with load capacity of 50 KN at a speed of 3 mm/sec. Spot welding samples showing an overlap of 40 mm with .08 mm thickness are shown in Fig 1.

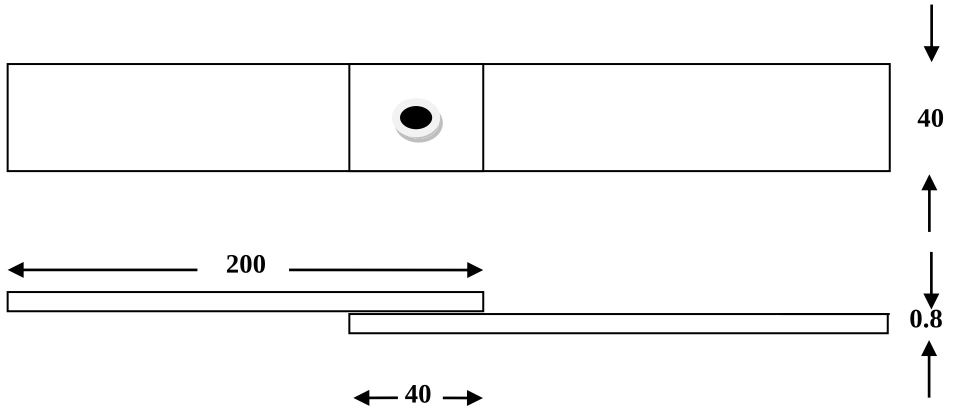

Fig 1. Spot welding samples showing an overlap of 40 mm with 0.8 mm

2.2 Result of Study

In the experimental setup, maximum short circuit current was varied for spot welding joints with constant hold time. Test results show that at lower values of time (≤ 1 sec) proper weld could not be established and value of breaking load increase with increase in welding current until optimized values. Load values decrease after optimized values as expulsion takes place at higher current. Table 1 shows the variation in current and resulted tensile loads. The shear values are shown in figures 2 with optimum values recorded at time 1.5 sec and weld current of 46 KA. Table 2 shows the effect of change in thickness of sheet on breaking load. The data shows similar pattern where values around 46~47 KA are optimized for spot weld. Set of values and results are shown in table 2 and Fig 3. Results from Sintech UTS at 44 KA and 1.5 sec are shown in Fig 4.

Table 1: Change in Current Values and Effects on shear strength (sheet thickness 0.8 mm**)**

S/No	Current Values (KA)	Time (Sec)	Sheet Thickness (mm)	D=Nugget Dia (mm)	Tensile load (N)
J 1	30	1.5	0.8	4.20	4608
J 2	35	1.5	0.8	4.8	4383
J3	40	1.5	0.8	6.70	4732
J4	42	1.5	0.8	6.0	4930
J5	44	1.5	0.8	5.58	5171
J6	45	1.5	0.8	6.8	5247
J7	46	1.5	0.8	6.6	5449
J8	47	1.5	0.8	6.9	5733
J9	50	1.5	0.8	6.6	5382

Table 2: Change in Current and Effects on shear strength (sheet thickness 1.0mm**)**

S/No	Current Values (KVA)	Time (Sec)	Sheet Thickness (mm)	D=Nugget Dia (mm)	Tensile load (N)
K 1	35	1.5	1	4.99	9582
K 2	38	1.5	1	4.64	9432
K 3	40	1.5	1	5.33	9899
K 4	42	1.5	1	6.17	9414
K 5	45	1.5	1	6.76	10349
K 6	47	1.5	1	6.89	10395

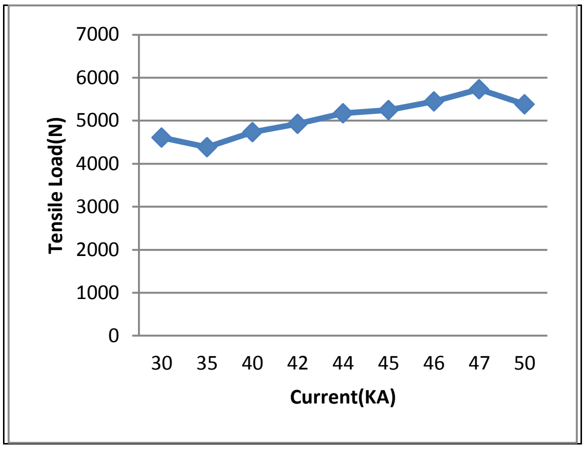

Fig 2: Graphs showing data from table 1 with nugget Dia and Tensile Loads (N) Sheet Thickness (0.8mm)

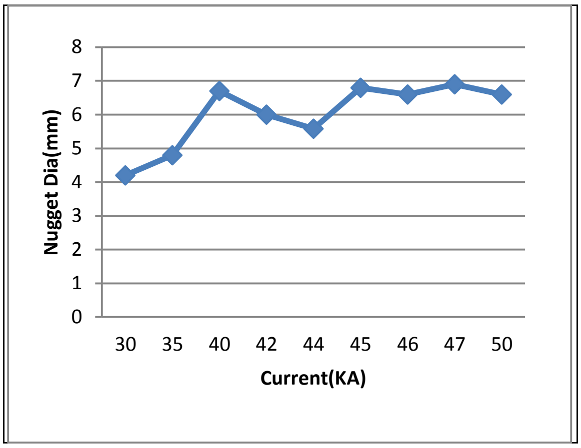

Fig 3: Graphs showing data from table 2 with nugget Dia and Tensile Loads (N)

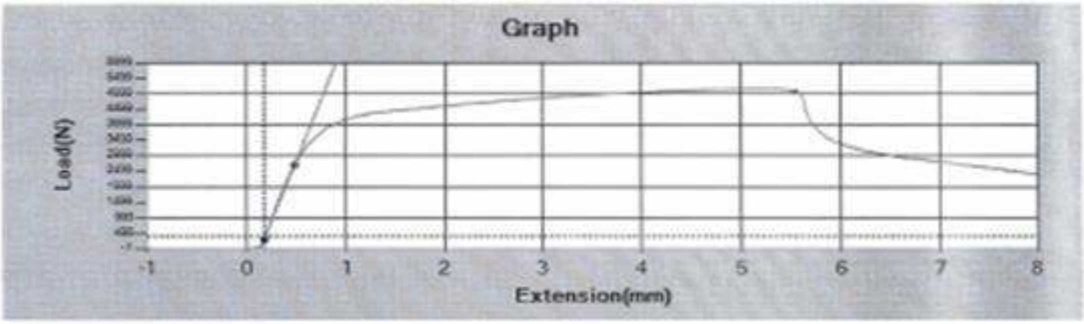

Fig 4: Experimental results showing shear load at 44 KA 1.5 sec

Samples were subjected to microscopic analysis through optical microscope (200 X). Observations were recorded and effects are shown in Fig 5 and Fig 6.

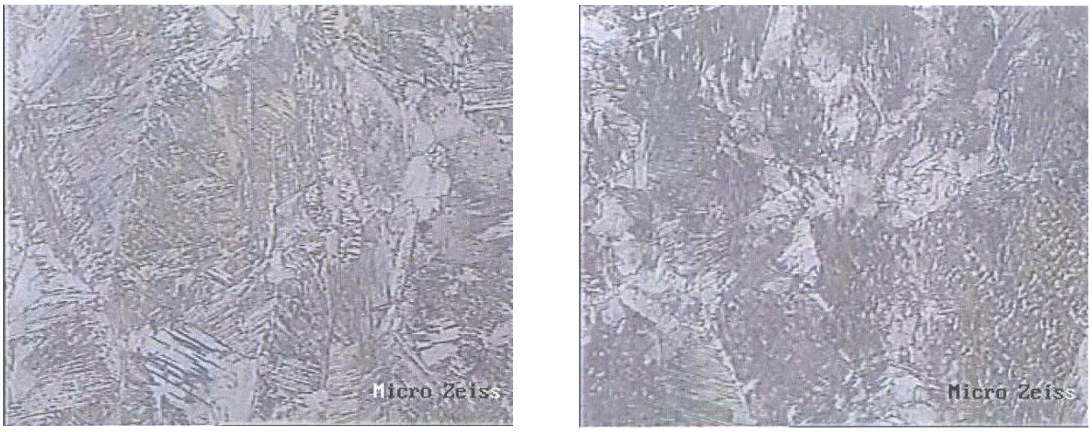

Fig 5: Micrograph showing micro structure in low carbon steel thickness 0.8 mm (45 and 47 KA)

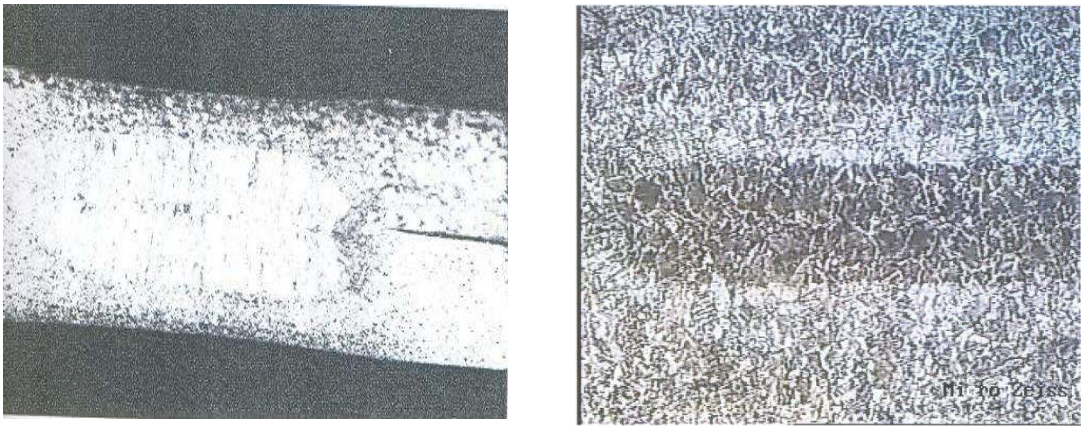

Fig 6: Micrographs showing micro structure in low carbon steel with columnar growth pattern in the fusion zone visible at low magnification and 47 KA

2.3 Microstructure Analysis

The above micrographs explain the development of spot welded microstructure from lowest values of hold current to the optimized values of spot welding samples. The base metal shows ferritic micro structure with fine pearlite at grain boundaries. As the higher current is passed through for spot welds, it can be seen that austenite steel (γ)is cooled down that results into nucleation of ferrite iron (α) at grain boundaries. As the current values are increased , micrograph shows typical weld microstructure in low carbon steel that consists of grain boundaries ferrite(15%) ,Widman statten ferrite(20%) ,acicular ferrite, upper bainite and significant growth of pearlite(up to 40%) from lower values. At the optimized values of time 1.5 sec and current 47 KA the spot weld shows typical weld microstructure in low carbon steel that consists of grain boundaries ferrite(5%) ,Widmanstatten ferrite(15%) , acicular ferrite(10%) , upper bainite (15%)and pearlite(45%). Figure 6 further elaborates showing of penetration and columnar growth pattern of ferrite in the fusion zone due to heating and optimized weld quality. Similar growth pattern can be seen in the first micrograph [8].Samples were prepared with Etchant 85 mL, H_2O+15 mL HNO3+5 mL methanol.

3. Optimization Results and Summary out put

3.1 Nugget Dia

Optimum process parameters were calculated through Minitab software and Regression equations for Nugget Diameter, breaking load and Tensile strength were obtained:

Nugget Dia = 3.29 – 0.0225 weld cycle + 0.0287 Hold Cycle + 0.066 Squeeze Cycle + 0.0596 Current

Table 3: Analysis of Variance

Source	DF	SS	MS	F
Regression	4	5.5377	1.3844	8.99
Residual Error	22	3.890	0.1540	
Total	26	8.9267		

3.2 Breaking Load

Load = 2819 – 2.3 weld cycle – 7.5 Hold Cycle + 87.8 Squeeze Cycle + 31.5 Current

Table 4: Analysis of Variance

Source	DF	SS	MS	F
Regression	4	3511278	877819	9.37
Residual Error	22	2060855	93675	
Total	26	5572133		

3.3 Tensile Strength

Tensile Strength = 166 + 0.425 weld cycle – 0.994 Hold Cycle + 1.15 Squeeze Cycle - 0.466 Current

Table 5: Analysis of Variance

Source	DF	SS	MS	F
Regression	4	103.47	25.87	0.91
Residual Error	22	622.71	28.30	
Total	26	726.18		

Tensile strength ranges from 147 ≤ Strength ≥ 159.4 where time was divided into weld cycle values between 25 ≤X1≥ 39, hold cycle 15≤X2≥23, squeeze cycle 10 ≤X3≥ 18, current 32 ≤X4≥50 and nugget diameter from 5.5≤Dia≥7.5. GA optimization results at various levels are tabulated [9]. These values are slightly higher than the optimized values , however within quality parameters suggested in spot welding standards(minimum 3 mm and maximum 7 mm).

Table 6: GA Optimization Results

Generation	**X1**	**X2**	**X3**	**X4**	**Nugget Dia**
250	35	18	16	40	7.2
500	32	17	11	47	7.33
1000	26	20	14	40	7.4

5. Conclusion

Weld current plays an important role in the spot weld quality. Although only one aspect of increasing weld current vis-à-vis plate thickness was recorded, another factor namely electrode force may be analyzed for future study. The current study was conducted on samples having thickness in the range of 0.8~1.0mm, where uniform value of shear strength was obtained. In the next study, electrode force will be used to analyze the effects of HAZ, current and weld strength Vis-à-vis Response Surface Methodology (RSM) in which solution of problem shall be obtained through approximating the unknown with and appropriate empirical model.

References

[1] Pardeep M, Mahesh N, Hussain Raja, Process parameters optimization in resistance spot welding of dissimilar thickness materials, Journal of Mechanical, Aerospace, Industrial Engineering Vol 8 No 1, 2014

[2] Arumugam A, Mohd Amizi N, Spot welding parameter optimization to improve weld characteristics for dissimilar metals, Journal of Scientific and Technology Research Vol 4, 2015 December 2009

[3] Correia D.S,Goncalves C.V, Cunha S.S, Ferraresi V.A, Comparison between Genetic Algorithm and Response Surface Methodology in GMAW welding Optimization , Journal of Material processing Technology 160(2005)70-76

[4] D.S Clark. Physical Metallurgy for Engineer, 1952 Litton Educational publishing Co.
10 Davis Drive, Belmount California, 94002

[5] J.Xu, X.jiang, Q.Zeng, T.Zhai, T.Leonhardt, J.Farrell, W. Optimization of resistance spot welding the assembly of refectory alloy50Mo-50Re thin sheets, Journal of Nuclear Materials, 366, 417-425, 2007.

[6] D.Steinmeier.Validating the resistance welding process.Welding Journal, December, 2009

[7] DeGarmo, J.Black, R. Kohsere, “Material & Processes in Manufacturing” Prentice Hall pp 999~1000 (1997)

[8] ASM handbook on Metallography and Microstructures, Vol 9,pp 586,1998.

[9] Panchakshari A, Kadam M , Optimization of the process parameters in resistance spot welding using Genetic Algorithm, Journal of Multidisciplinary Science and Engineering Vol 4 No 3, March 2013