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Developing Controller and Optimizing Parameters for Improving Tensile Strength and Heat Affected Zone of Spot Welded Joint using Grey Based Taguchi Method

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Abstract: **-- In the first part of the present work, a controller was developed and mounted on a pedal operated spot welding machine to control weld time, hold time and squeeze time. Later, the machine was used to optimize the welding parameters to improve the Tensile Shear Strength (TSS) & reduce Heat Affected Zone (HAZ) of spot welded joint between dissimilar metallic sheets of stainless steel and mild steel each of thickness 1 mm. The four input parameters weld time; hold time, weld current & electrode force were selected. Grey based Taguchi method was applied with L_{27} orthogonal array & MIITAB 17 software was used to perform Analysis of Variance (ANOVA).Weld time was found to be the most significant parameter. The Grey Relational Grades obtained from the confirmation experiment was found quite close to that calculated for optimal combination (A_1, B2, C3, D2).**

Index Terms: **— Dissimilar metallic sheets, Tensile Shear Strength, Heat Affected Zone, Grey relational analysis, Analysis of Variance.**

I. INTRODUCTION

Resistance spot welding is well accepted process for joining sheet metal components. Automobile industry is one of the largest users of spot welding due to its flexibility, robustness and speedy welds on metallic sheet components. A typical automobile embraces 6000 to 8000 spot welds. Though welding of components of similar metallic sheets are popular yet joining of dissimilar metallic components are progressively enhancing mainly due to economy and low weight requirements. Various models were proposed by researchers to study micro structural changes and changes in mechanical properties across the joint between similar and dissimilar metals with same and different thicknesses. Quality of welded joint is assessed by various quality characteristics like tensile shear strength, heat affected zone, nugget diameter, hardness and micro structural changes across the joint. Strength is most coveted property of welded joint that ensures the satisfactory performance of the joint during service. Researchers have applied Taguchi and Grey Taguchi methods to study the effect of various parameters on quality attributes of spot welded joint between similar and dissimilar metals. Effect of welding current, welding time, electrode diameter and electrode force on tensile shear strength of joint between galvanized steel sheets [1], tensile shear strength and nugget size under the effect of pressure , weld current and weld time on stainless steel joint [2], effect of welding current and weld time on nugget diameter and tensile shear strength of joint between SPRC35 steel sheets [3], weld nugget and heat affected zone of joint for weld current, weld and hold time between low carbon steel sheets [4], strength, nugget diameter and weld indentation for weld between SPHC and SPRC steel sheets [5].Failures modes along with hardness variation across spot welded nuggets between mild steel and stainless steel sheets under variation of weld current and time were observed without using systematic experimentation approach [6].One of the early works of investigating tensile strength of spot welded joint using design of experiments considered five process parameters. [7].The influence of process parameters on quality characteristics were studied for other welding processes as well. Heat affected zone and bead geometry in submerged arc welding [8] and flux cored arc welding [9] of mild steel plates, bead width, depth of penetration and aspect ratio in laser beam welding and spot diameter in MIG spot welding between stainless sheets and low carbon steel [10**]**.The effect of beam power, travel speed and focal position on bead width, depth of penetration and aspect ratio for spot welded joint between stainless steel sheets were studied for laser beam welding [11]. Failure modes under overload conditions were studied for Laser spot welded joints between low carbon steel sheets under five process parameters [12].

II. DEVELOPING CONTROLLER

The present work can be classified into two parts. In the first part, controller for the pedal operated spot welding machine was developed for setting and controlling the weld time and hold time. The controller consists of:

a. Microcontroller

It's the main component of the controller. Atmega328 is used that has a low-control CMOS 8-bit microcontroller having a rich direction set with 32 broadly useful working registers. All the 32 registers are straightforwardly associated with the Arithmetic Logic Unit (ALU), permitting two autonomous registers in one single direction executed in one clock cycle. The Atmega328 includes the accompanying elements: 32Kbytes of In-System Programmable Flash Program memory with Read-While-Write capacities, 1024bytes EEPROM, 2Kbyte SRAM, 32 broadly useful I/O lines, 20 universally useful working registers, a JTAG interface for Boundary filter, On-chip Debugging backing and programming, three adaptable Timer/Counters with look at modes, Internal and External Interrupts, a serial programmable USART, a byte arranged two-wire Serial Interface, a 6-channel, 10-bit ADC with discretionary differential information stage with programmable addition (TQFP bundle just), a programmable Watchdog Timer with Internal Oscillator, a SPI serial port, and six programming selectable force sparing modes. It is used for controlling timing of the three cycles. After having achieved a satisfactory simulated version using Proteus, the hardware portion was started. The layouts were prepared with the help of Proteus and traced on PCB with pressured heating technique. After having tested the PCB for proper weld timings, actual tests were made on the spot welding machine in the work shop. The device is now capable of controlling the weld cycle timing with maximum weld time being 2 second. Microcontroller board incorporates two distinct circuits-

1. Zero cross detector circuitry

The term zero cross detector is related and used in image processing, mathematics and in electronics. Zero crossing in mathematics is a point where sign of function changes from positive to negative and vice versa, expressed by axis crossing in the graph of function. Zero cross circuit avoids the sparking by supplying the current to solid state relay at zero crossing of mains supply.

2. OPTO-coupler

OPTO-coupler isolates the two circuits one working at higher voltage (on controlled side) and the other at lower voltage (on controlling side) to shield low voltage circuit during the yet maintaining the connection between the two. In the present case, the microcontroller circuit is controlling the timings of high current flow to welding machine through solid state relay. Opto-coupler circuit is shown in Fig. 1.

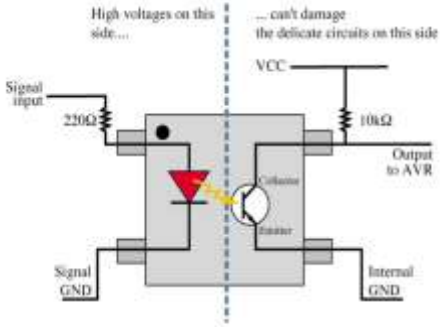

Fig. 1 Opto-coupler circuit

B. Solid state relay

Solid State relay is an electronic switching device that controls a large current or voltage using a control signal. Fig. 2 shows its schematics. It consists of - i) Voltage or current sensor that is activated by an appropriate control signal ii) a solid state electronics that switches the power ON or OFF to the load circuit iii) a mechanism that facilitates the control signal to activate solid state relay. The solid state relay is designed to supply AC to the load similar to electro-mechanical rely but without any moving part. Here it will control the number of cycles of weld timing as per the instructions of the microcontroller. Fig. 3 shows the actual controller.

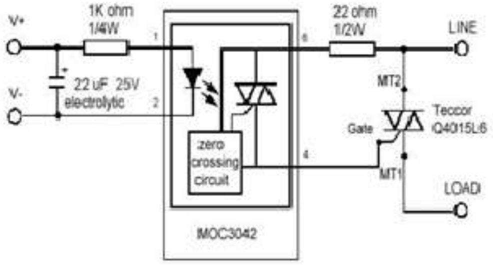

Fig. 2 Solid state relay

Fig. 3 The actual controller

C. Working of the Controller

The following flowchart in Fig. 4 shows the working of the controller:

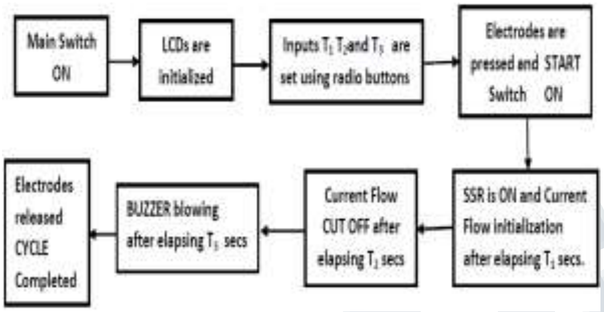

Fig. 4 Flow chart of working of controller

III. EXPERIMENTATION

In the second part, spot welded samples of mild steel with stainless steel sheets were developed as per L_{27} orthogonal array. The experimental set up consists of pedal operated spot welding machine mounted with developed controller and spring balance. Spring balance measures the electrode force in kgf. Fig. 5 shows the pedal operated machine mounted with controller and spring balance for measuring electrode force. Fig. 6 shows the schematics of work specimen dimensions and fig. 7(a) and (b) show the actual specimen in original and broken condition.

Fig. 5 Pedal operated spot welding machine

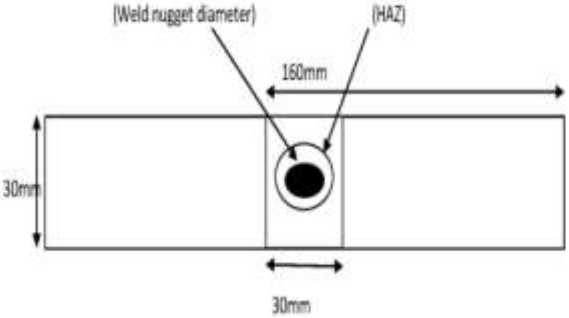

Fig. 6 Schematics of work sample

(a) (b)

Fig. 7 (a) Welded specimen (b) Broken specimen

Select quality characteristics

The quality characteristics selected in the present study are – tensile shear strength (TSS) and heat affected zone (HAZ) around the welded joint.

B. selecting control factors& their levels

Weld time, hold time, weld current and electrode force were selected as control factors at the levels shown in Table. 1.

Table. 1. Input parameters with their respective levels

L	(A)	(B)	(C)	(D)
1	10	10	2044	19.81
2	30	30	2628	39.65
3	50	50	3650	59.48

Where,
L= levels, A= weld time in cycle, B= hold time in cycle= weld time in cycle, C= weld current in ampere D= electrode force in Newton.

C. Selection of orthogonal array and conducting experiments

$L_{27}$was selected as the orthogonal array to design the experiments. Each experiment was performed thrice and the average values of observations are posted in Table 2. The heat affected zones on specimens were measured by vernier callipers immediately after the welding was over. The tensile shear strengths were measured at UTM. The developed and the broken samples are shown in Fig. 7 (a) and (b).

D. Evaluating S/N ratios and normalised values

Signal to noise ratio (η) is the main contribution of Taguchi's method and is used for identifying quality characteristics. It is the ratio of "signal" which represents desirable value to "noise" which represent undesirable value. Quality characteristics categorized in to Higher the Best (HB), Lower the Best (LB) and nominal the best (NB), according to the equations (1) and (2) .In this study, tensile shear strength is preferred as Higher (HB) and HAZ as Lower the Best (LB).

- Higher the better

$$\eta = -10 \log \frac{1}{N} \sum_{i=1}^{n} \frac{1}{Y^2} \text{ .... (1)}$$

- Lower the better

$$\eta = -10 \log \frac{1}{N} \sum_{i=1}^{n} Y^2 \text{ .... (2)}$$

Signal to noise ratio and normalized values for tensile shear strength and HAZ are evaluated and posted in Table 3 & 4. The normalised values are calculated by equations (3) and (4) for the measured values of quality characteristics.

- For Higher the better

$$x_i^*(k) = \frac{x_i^{(0)} - min\, x_i^{(0)}(k)}{max\, x_i^{(0)}(k) - min\, x_i^{(0)}(k)} \text{... .... (3)}$$

- Lower the better

$$x_i^*(k) = \frac{max\, x_i^{(0)} - x_i^{(0)}(k)}{max\, x_i^{(0)}(k) - min\, x_i^{(0)}(k)} \text{..............(4)}$$

E. Evaluation of Grey Relational Coefficient and Grey Relational Grades

After calculating normalized values for the two quality characteristics, grey relational coefficients (GRC) and grey relational grades (GRG) were calculated. Grey relational coefficients are determined from equation (5)

$$\xi_i(k) = \frac{\Delta_{min} + \zeta \Delta_{max}}{\Delta_{0i}(k) + \zeta \Delta_{max}} \text{......................... (5)}$$

Where, ζ is distinguishing coefficient & it is taken as 0.5.

After calculating GRC for both responses, the grey relational grade was determined by averaging the value of GRC of tensile shear strength and heat affected zone. The values of Grey Relational Coefficients and Grey Relational Grades are also posted in Table.4 & 5. Higher values of grades correspond to closeness to optimal combination of input parameters and so the highest value of grade correspond to the optimal combination of parameters.

IV. RESULTS AND DISCUSSION

A. Optimal factor level combination

Experiments under optimal factor-level combination generate highest grey relational grade and hence desired performance. The average grey relational grades were calculated for each factor at its three levels and are posted in Table. 6. The average grey relational grade for the factor A i.e. weld time for level 1, 2 and 3 are determined by averaging the values of grades for the experiments (1-9), (10-18) and (19-27) respectively. The highest values of grade for each of the factor corresponding to each level decide the optimal factor-level combination and also establish the relative importance of factors. The optimal factor-level was found out combination is – A_1, B_2, C3, D2.

Table. 2. Values of TSS & HAZ

R	TSS (KN)	HAZ (mm)
1	1.7	2.7
2	1.8	2.6
3	2.4	3.4
4	2.4	3.0
5	2.3	3.5
6	2.9	3.7
7	2.5	3.3
8	2.2	2.8
9	3.4	3.9
10	3.4	5.8
11	3.9	5.8
12	4.1	5.7
13	3.5	5.4
14	3.5	5.3
15	4.2	5.7
16	3.3	5.3

17	3.4	5.6
18	3.9	5.8
19	3.6	6.5
20	3.4	6.7
21	4.0	7.7
22	4.3	6.8
23	4.2	6.8
24	4.5	8.6
25	4.2	7.2
26	4.3	7.1
27	4.4	7.9

Where,
R= no. of runs or experiments

Table. 3. Values of S/N ratios

R	S/N ratios	
	TSS	**HAZ**
1	4.61	-8.63
2	5.11	-8.30
3	7.60	-10.53
4	7.60	-9.63
5	7.23	-10.78
6	9.25	-11.36
7	7.96	-10.26
8	6.85	-9.04
9	10.63	-11.73
10	10.63	-15.21
11	11.82	-15.21
12	12.26	-15.16
13	10.88	-14.70
14	10.88	-14.49
15	12.46	-15.16
16	10.37	-14.49
17	10.63	-14.90
18	11.82	-15.31
19	11.13	-16.30
20	10.63	-16.56
21	12.04	-17.73
22	12.67	-16.65
23	12.46	-16.69
24	13.06	-18.69
25	12.46	-17.15
26	12.67	-17.03
27	12.87	-17.95

Table. 4. Normalized values & GRC

Normalized Values		GRC	
TSS	**HAZ**	**TSS**	**HAZ**
0.00	0.983	0.33	0.97
0.03	1.000	0.34	1.00
0.25	0.873	0.40	0.80
0.25	0.928	0.40	0.87
0.21	0.857	0.39	0.78
0.42	0.817	0.47	0.73
0.28	0.890	0.41	0.82
0.17	0.962	0.38	0.93
0.60	0.790	0.56	0.70
0.60	0.473	0.56	0.49
0.78	0.473	0.70	0.49

0.85	0.478	0.78	0.49
0.64	0.528	0.58	0.51
0.64	0.550	0.58	0.53
0.89	0.478	0.82	0.49
0.57	0.550	0.54	0.53

12	0.634
13	0.549
14	0.555
15	0.656

Factors	DOF	SS	MS	F-value	% C
A	2	0.012573	0.006286	2.56	18.31
B	2	0.004666	0.002333	0.95	6.80
C	2	0.005516	0.002758	1.12	8.03
D	2	0.001638	0.000819	0.33	2.39
Error	18	0.068661	0.002459		64.47
Total	26				100

0.60	0.507	0.56	0.50
0.78	0.462	0.70	0.48
0.67	0.345	0.61	0.43
0.60	0.312	0.56	0.42
0.82	0.150	0.74	0.37
0.92	0.300	0.88	0.42
0.89	0.295	0.82	0.41
1.00	0.000	1.00	0.33
0.89	0.233	0.82	0.39
0.92	0.250	0.88	0.40
0.96	0.117	0.93	0.36

Where,
GRC = Grey Relational coefficient

16	0.532
17	0.532
18	0.591
19	0.521
20	0.490
21	0.554
22	0.646
23	0.619
24	0.667
25	0.609
26	0.638
27	0.647

Table. 5. Values of GRG

R	GRG
1	0.651
2	0.671
3	0.599
4	0.637
5	0.583
6	0.599
7	0.616
8	0.654
9	0.632
10	0.524
11	0.594

Where,
GRG = Grey Relational Grade

Table. 6. Average Grey Relational Grades

	L1	L2	L3	Max.-Min.	Rank
A	0.627	0.508	0.593	0.118	1
B	0.582	0.612	0.606	0.031	3
C	0.587	0.593	0.620	0.033	2

D	0.604	0.606	0.589	0.017	4

Where,
L1, L2, L3= Levels of parameter

B. predicting the optimal performance

Under the optimal factor-level combination, the highest grey relational grade was predicted by using eq. (6)

Predicted mean grade $\mu = \overline{A}1 + \overline{B}2 + \overline{C}3 + \overline{D}2 - 3(Tgg)$ ………….. (6)

$\mu = 0.684$

C. Analysis of Variance

ANOVA is a statistical tool used to identify the significant factors and their contributions. The calculations of ANOVA based on grey relational grades are illustrated in Table 7. It was obvious that weld time (A) was found to be most significant factor with contribution of 18.31% followed by weld time (C) with 8.03% and hold time with 6.80 % (B). Electrode force (D) was found to be the least significant factor with 2.39 % contribution.

Table. 7. ANOVA Table

D. confirmation test

Confirmation test validates the predicted value of grade and yields corresponding improved values of the two responses under optimal factor-level combination. Table.8 & 9 incorporates the values of performance characteristics and grey relational grades. Finally, the performance under optimal conditions was compared with that under designated conditions and that under designated conditions ($A_2B_3C_3D_2$).

Table. 8. Confirmation table for TSS & HAZ

Exp.	TSS (kN)	Avg. TSS	HAZ (mm)	Avg. (HAZ)
1.	4.1	23	5.3	5.20
2.	4.2		5.4	
3.	4.4		4.9	

Table. 9. Confirmation table for GRG

Exp.	GRG	Avg. GRG
1.	0.652	0.691
2.	0.670	
3.	0.749	

Obviously, under optimal conditions, the predicted grey relational grade was higher than any of the grades mentioned in the table .9 or that mentioned in table .7 and represents the highest possible grade for this experimentation. The average value of experimental grades i.e. 0.691 lies within the two limits and reflects a close proximity with the predicted grade 0.684 and a noted difference of 0.1 With that obtained under designated condition (A_2,B_3,C_3,D_2). The average values of TSS and HAZ from experiments under optimum conditions were found to be 4.23 kN and 5.2 mm. respectively which posts an improvement of 8.4 % in TSS and 10.3% in HAZ as compared to the corresponding values under designated conditions.

Table. 10. Performance characteristics

Parameters under comparison	Designated conditions	Optimal Welding Parameters	
		Predicted values	Confirmation values
Levels	$A_2B_3C_3D_2$	$A_1B_2C_3D_2$	$A_1B_2C_3D_2$
TSS (kN)	3.90	-	4.23
HAZ(mm)	5.83	-	5.20
GRG	0.591	0.684	0.691
Improve in GRG	0.10		

V. CONCLUSION

Product quality is the key issue in today's competitive environment. Though various quality checks from raw material procurement up to delivering finished product are performed, rejections are inevitable. Quality checks increase the product cost in terms of cost of inspection and increased manufacturing lead time. Efficient use of manufacturing resources depend on selection of influencing process parameters and strictly maintaining them during the process which was earlier dependent on experience of process supervisor. Grey based Taguchi, a hybrid method, has emerged a powerful offline quality tool suitable to optimize two or more parameters simultaneously. It has provided scientific way for the selection of process parameters and their levels and has guaranteed improved product quality in the form of desired characteristics. The successful implementation of the tool for the process demand careful selection of process parameters and may need a rigorous effort to establish the process. In present work, Grey based Taguchi methodology has been applied successfully to explore spot welding process for improving two quality characteristics simultaneously. However, it is expected that the results can be improved by considering the interactions between the factors which was not considered here.

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