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The Experimental Investigation and Analysis of Spot Welding Process Parameters for Maximum Tensile Strength

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Abstract:* *This experimental study is based on an investigation of the effect of welding parameters on tensile shear strength in the resistance spot welding (RSW) process and optimization of welding parameters. The experiment conducted under varying parameters like forces, currents and weld times without disturbing water flow and room temperature. The setting of welding parameters was determined by using Taguchi experimental design of L9 orthogonal array method. The combination of the optimum welding parameters has determined by using analysis of Signal- to- Noise (S/N) ratio. The experimental result clearly shows that it is possible to increase the tensile shear strength of a joint by the combination of suitable welding parameters. Hence the experimental result proved the validity of the used taguchi method for enhancing the welding strength performance and optimizing the most suitable welding parameters in resistance spot welding operations.

Keywords:* *Resistance Spot Welding (Rsw), S/N Ratio, Taguchi Method, Optimization, Tensile Strength.

I. INTRODUCTION

Resistance Spot Welding (RSW) is among the oldest of the electric welding method that used in the industry and it is a useful and accepted method of joining metal. Resistance spot welding (RSW) is a process in which metal surfaces are joined in one or more spots. As the name suggest it works on the principle of resistance to the flow of electric current through workpieces that are held together under force by electrodes. The weld is made by a combination of heat, pressure, and time. The process is used for joining sheet materials and uses shaped copper alloy electrodes to apply pressure and convey the electrical current through the workpiece. Heat is developed mainly at the interface between two sheets, eventually causing the material being welded to melt, forming a molten pool, the weld nugget. The molten pool is contained by the pressure applied by the electrode tip and the surrounding solid metal. The resistance spot welding has the advantage which is high speed and suitability for automation. Resistance spot welding is getting significant importance in the car, bus and railway bodies etc. due to automatic and fast process. The major factors controlling this process are the current time, electrode force, contact resistance, the property of electrode material, sheet materials, surface condition etc. the quality is best judged by nugget size and joint strength. This study presents a systematic approach to determine the effect of process parameters (electrode force, weld time and current) on the tensile shear strength of resistance weld joint of mild steel using Taguchi method. A general introduction to principle, working, and parameters of spot welding are given below.

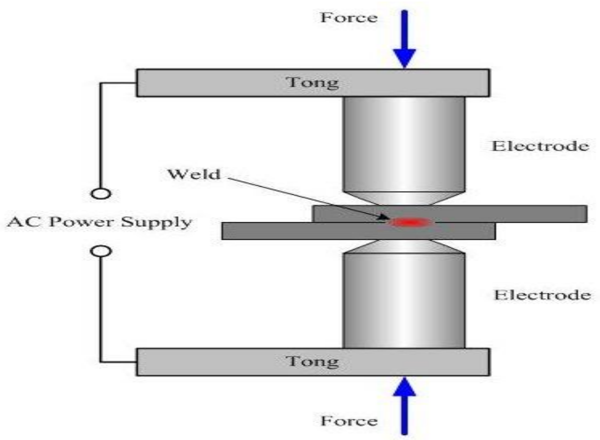

Fig. 1 Spot Welding Process

A. The operation principle of Resistance Spot Welding process.

Resistance Spot Welding (RSW) is thermo-electric processes where heat is used in joining the work parts of metal. Heat is generated from electrical resistance across the two work parts. In Resistance Spot Welding to work part of metal are joined together by supplying electric current and pressure in the zone to be weld and resistance welding is different From arc welding because it's not required filler metal or fluxes added to the weld area during the welding process. So that RSW process is widely used.

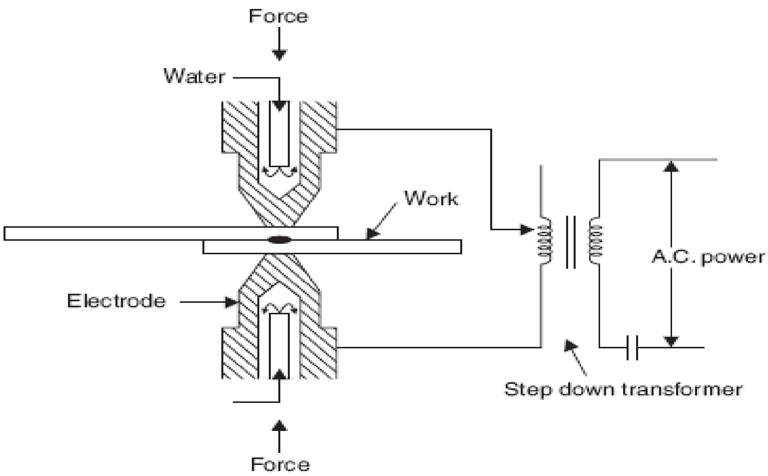

Fig. 2 Resistance welding machine circuit

Resistance Spot welding is widely used in automobile sector because the operations are easy to perform and fast production can be achieved than any other welding process.

Resistance spot welding process are based on four main factor as mentioned below

1) The amount of current that passes through the workpiece.
2) The pressure that the electrodes applied on the workpiece.
3) The time the current flow through the workpiece
4) The area of the electrode tip contact with the workpiece

The welding force is applied by leg pedal. Squeezing the electrode to the workpieces, the right amount of pressure that applied on the workpieces is very important in order to obtain the good quality of welds. During the welding process, the electric current flows through electrode tips to the separate workpieces of metal to be joined.

The resistance of the base metal to electrical current flow causes heat, the heat is limited to the area which the tip of the electrode and weld area contacts. While the welding force is maintained, the heat is generating. In the holding stage (where the pressure is still maintained), the current is switched off and the nugget is cooled under the pressure. The heat that generated in spot welding basically depends on the electric current and the time being used and on the electrical resistance of the material between electrodes. The amount of heat generated is a function of current, time and resistance between the electrode the heat that generates in resistance spot welding according to Joule's law is expressed by the Equation.

H= **I2RtK**

Where

H = Heat is generated in joules
I = Current (in amperes) *R* = Resistance (in ohms)
t = Time to current flow (in seconds)
k= thermal constant.

II. LITERATURE REVIEW

A change in the welding schedule that comprises a change in current with time at constant pressure shows changes in the amplitudes of both the current and voltage waveforms. Atzori et al. [1] investigated the effect of nucleus diameter, heights of the nucleus, nucleus size on mechanical properties i.e. tensile shear and tensile peel strength in electrical resistance spot welding of galvanized chromed micro alloyed steel sheets. Hirch et al. [2].To study of mechanical strength for three test geometry lap-shear, cross-tension and coach-peel, For lap shear strength, a strong relationship with weld nugget diameter was observed; whilst discrete strength levels were found for coach-peel test geometry. For cross-tension strength; there is a relationship with nugget diameter; but data are sensitive to nugget periphery defects (L. Han, M. Thornton, D. Boomer, M. Shergold, 2011) [2]. Experimental and modeling investigation of the failure resistance of Advanced High Strength Steels spot welds (S. Dancette et al, 2011) [3].Contact conditions on nugget development during resistance spot welding of Zn-coated steel sheets using rounded tip electrodes and compared to the flatted tip electrode, analysis has to be carryout (R. Raoelison, A. Fuentes, 2012) [4].

III.METHODOLOGY

A. Planning

1) Selection of preferred values of Input parameters (Electrode force, welding current, welding time,)-Based on the literature review the preferred values for the current experiment are selected as follows. In Resistance spot welding machine, use of high electrode force, high current and low welding time and low holding time are recommended to obtain high tensile strength for the specific test range in a specified material.

TABLE I
PROCESS PARAMETERS AND THEIR VALUES

Parameter Setting	Unit	Preferred Values		
electrode force	KN	0.78	0.83	0.92
Current	KA	9	10	11
welding time	Cycle	5	10	15

Selection of Material Plate of Cold rolled carbon Steel. For the present work the material use is CRC Plate of Steel in the dimensions (250 mm × 25 mm × 1.2 mm), and (250 mm × 25 mm × 1.5 mm).The physical properties of the material are as follows

TABLE II
PHYSICAL PROPERTIES OF THE MATERIAL

Physical Properties	CRCS
Hardness	50 HRB (94VPN)
Ultimate Tensile strength	310 N/mm^2
Yield strength	210 N/mm^2
Carbon	0.08
Mn	0.4
Sulphur	0.03
Phosphorous	0.03

2) Selection of orthogonal array (3*3=L9 Orthogonal Array)

Classical experimental design methods are too complex and are not easy to use. A large number of experiments have to be carried out when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. According to the Taguchi method, a robust design and an L9 orthogonal array are employed for the experimentation. Four machining parameters are considered as controlling factors – namely, force, current, welding time, and each parameter have three levels – namely low, medium and high, denoted by 1, 2 and 3, respectively. Orthogonal arrays are a special standard experimental design that requires only a small number of experimental trials to find the main factor effects on output. Before selecting an orthogonal array, the minimum number of experiments to be conducted shall be fixed which is given by:

$$N\,Taguchi = 1 + NV\,(L - 1)$$

Where,
N Taguchi = Number of experiments to be conducted
NV = Number of variables = Number of levels
Hence at least 3 trials for each level, 9 trials for each material and total 18 trials are supposed to be conducted for the present project work. Based on this orthogonal array (OA) is to be selected which has at least 3 rows i.e.,3 experimental runs. Standard OAs available are L4, L8, L9, L12, L16, L18, L27, etc once the orthogonal array is selected, the experiments are selected as per the level combinations. The number of DOF for orthogonal array should be greater than or equal to the number of DOF required.

B. ACTUAL EXPERIMENTATION

While performing actual experimentation the specification of the machine should be taken into account the specification of the machine taken for trial is as shown in the following table.

TABLE III
TECHNICAL SPECIFICATION OF RSW MACHINE

Make and Model	WELDON INDIA-75
Technical Specifications	
Rated input voltage	415 V
Nominal power in KVA	75
Cylinder dia. X Stroke in mm	150 X 80
Electrode tip dimension dia.in mm	19
Cooling water volume	10Ltr/min
Machine size in mm	490 X 1390 X 1750

Fig. 3. Resistance welding machine (WELDON INDIA-75)

C. MEASURING RESPONSES

Tensile strength test is carried out by using universal testing machine and analysis to be carried out using Minitab software.

D. Signal to Noise ratio

The S/N ratio is a concurrent quality metric linked to the loss function. By maximizing the S/N ratio, the loss associated can be minimized. The S/N ratio determines the most robust set of operating conditions from variation within the results. The S/N ratio is treated as a response (transform of raw data) of the experiment. Through S/N data analysis aided by the raw data analysis Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. The loss function for the lower gives better performance characteristic and can be expressed as

$$L_{ij} = \frac{1}{n}\sum_{k=1}^{n} y^2{}_{ijk}$$

WhereLij is the loss function of the ith performance characteristic in the jth experiment, yijk the experimental value of the ith performance characteristic in the jth experiment at the kth trial and n the number of trials. The loss function is further transformed into an S/N ratio. The value of the loss function is further transformed into signal-to-noise (S/N) ratio. The rationale for this switch over to S/N ratios instead of working directly with the quality characteristic measurement is, the S/N ratio is a concurrent statistic –a special kind of data summary. A concurrent statistic is able to look at two or more characteristics of distribution and roll this characteristic into a single number or figure of merit. Usually, there are three categories of performance characteristic in the analysis of the S/N ratio

$$1. Target\ the\ best \quad \frac{S}{N} = 10 \log \frac{\bar{y}}{y\ s^2}$$

$$2. Target\ the\ best \quad \frac{S}{N} = -10 \log \frac{1}{n} \left[\sum \frac{1}{y^2} \right]$$

$$3. Target\ the\ best \quad \frac{S}{N} = -10 \log \frac{1}{n} \left[\sum y^2 \right]$$

In robust design, one minimizes the sensitivity of noise by seeking combinations of the design parameters setting that maximize the S/N ratio. The evaluation of surface roughness performed using the signal to noise ratio analysis is to determine which settings of the controllable factors results in the mean as close as possible to the desired target and a maximum value of the signal- to -noise (S/N) ratio.

TABLE IV
S/N RATIO OF EXPERIMENT PERFORMED

EXPERIMENT NO.	**S/N RATIO (db)**	
	1.2mm	**1.5mm**
1	**15.91**	**27.61**
2	**17.95**	**27.52**
3	**19.11**	**27.42**
4	**15.22**	**25.92**
5	**18.13**	**25.80**
6	**19.93**	**25.75**
7	**17.32**	**21.33**
8	**17.82**	**22.22**
9	**18.52**	**22.81**

Based on S/N ratio, new operation parameters were obtained through the maximum level of each parameter. Then the prediction of S/N ratio and tensile shear strength is calculated by using the following relationship

Ƞ = ηm + ∑ n i-1(a-m)

Where,

Ƞ = Predicted S/N ratio

ηm = Total mean of S/N ratio

a = Mean of S/N ratio at the optimal level

n = The number of main welding parameters, That significantly affects the performance.

TABLE V
S/N RATIO responses for tensile shear strength

Thickness	Symbol	process parameter	S/N Ratio (db)			Maximum-minimum
			Level 1	Level 2	Level 3	
1.2 mm	A	Electrode force	18.20	18.20	18.10	0.07
	B	Welding current	17.10	17.26	19.52	3.09
	C	Time	18.45	18.50	18.45	0.98
1.5 mm	A	Electrode force	22.53	22.90	11.00	12.75
	B	Welding current	18.20	19.00	20.00	1.85
	C	Time	18.00	19.10	18.95	0.20

CONCLUSIONS

The quality of spot welding depends upon the amount of tensile strength required to break the joint or to break the nugget. This experiment also results in the optimum process parameters to give the maximum tensile shear strength of spot welded joint. To perform a combination of different parameters, the Taguchi L9 orthogonal array has been adopted to perform the experiment. The mild steel specimen of 1.2mm*25mm*250mm and 1.5mm*25mm*250mm are used as a workpiece. Then tensile shear strength is calculated by the universal testing machine of each experiment. The optimum parameters combination are found out using S/N ratio. The result obtained shows that it is possible to increase tensile shear strength by using suitable parameters. At different parameters, there will be different tensile strength value. So that perfect combination of parameters is important to achieve maximum tensile shear strength.

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