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RELIABILITY STUDY ON RESISTANCE SPOT WELD PROCESS PARAMETERS IN AUTOMOBILE COMPONENTS

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Abstract In this research work design of experiments (DoE) methodology has been utilised for the optimisation of the resistance spot-weld (RSW) process parameters of the two Indian automobile manufacturers for their one millimetre thick steel sheet materials. For the optimised weld parameters and for the given road load data of these companies, Weibull plots have been analysed and reliability parameters for the basic design configurations have been evaluated. Based on these results recommendations have been made for implementation.

INTRODUCTION

Resistance Spot Welding (RSW) is used extensively to fasten sheet steels for automobile applications. In order to reduce weight of the vehicle the time tested and proven thick gauge carbon steel sheets is now being replaced by high strength steel sheets of thin gauges. Fatigue behaviour of spot welds is one of the primary parameters that governs the safety and reliability of the automotive vehicles. It has been reported that when sheet material of a particular automobile was almost entirely replaced by thin gauge high strength sheet and no other design modifications were made, the results of road tests showed fatigue damage at spot connections. This failure was attributed to the decrease in body stiffness caused by reduction in sheet thickness and the persistence of residual stresses in the stronger material [Yamamoto,1980]. In spite of the large number of research work done in the last two decades or so, for understanding the Spot Weldability of sheet steel, the intricacies of the RSW process and the effects of the interactions of the various factors on the spot weld strength is still not fully understood. [Dickinson and Natale,1981 and Reemsnyder,1992]

The RSW process basically involves a complicated interaction of thermal, electrical, mechanical, metallurgical as well as of contact surface characteristics. In the RSW process, a differential amount of internal heat is generated (in terms of Joule's heat) due to the flow of high amperage current depending on non-uniform current density distribution, varying material resistivity and contact resistance at sheet-steel as well as sheet electrode interfaces. The basic heat transfer in RSW is a combination of heat conduction and to a small extent, of heat convection during nugget formation. The plastic flow at the sheet electrode interface, due to electrode force and interface temperature, decides the actual sheet-electrode contact area, which influences the formation of current-carrying zone within the sheet. The tensile shear strength (TSS) increases directly with the weld diameter as current increases. Penetration or depth of fusion that extends into approximately 70% of the work piece thickness usually gives maximum strength. The weld-time and hold-time of the RSW have utmost importance in getting a sound weld for reliable performance in fatigue loading for automobile applications. Most portable-gun welding is done with less than 10 cycles of weld time and hold time for automotive applications, but in certain cases higher weld or hold time may be desirable. Longer hold time produces a faster cooling rate and a harder weld, which has a tendency of increased weld metal fracture. During crack growth, the opening of the crack advances the crack, while closure of the crack does not. Therefore, R ratios less than zero are not expected to influence fatigue-crack-growth performance [Davidson, 1983]. Tensile residual stresses approaching the yield strength of the material are commonly present in unstress-relieved spot welds. A considerable amount of experimentation is required to be conducted for optimisation of the basic weld parameters of RSW when material or the sheet thickness is changed.

METHODOLOGY

In Indian Automotive Industries RSW is done either through manual or semi-automatic machines. Very few car / jeep / truck producers are using automatic or robotic systems for RSW control. The "Weld Schedule" (i.e. number of cycles for squeeze time, heat / weld time, hold time and off time) is different for different material and thickness. Standards are available for most of the commercial sheet materials in the industry for the

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RSW weld schedule, electrode material, type of electrode etc. for manual and semi-automatic machines and adaptive control for automatic or robotic systems. However, new materials, or change in thickness or metallurgical processing of the sheet call for preparation of fresh weld schedule in order to suit the different loading conditions. Also changes in the loading conditions because of redesign may require different weld pitches. The Spot Weldability of sheet steel is commonly evaluated by a number of quality control and mechanical tests that have varying degrees of significance in terms of process control and service performance. In the automotive industry, ease of welding in the plant is a must if sound spot welds of adequate size are to be consistently produced at extremely high production rates. Welding procedures and tests must be such that production rates will remain high in spite of the customary variation in fit, thickness etc. The most commonly used spot-weld fatigue test specimen which has evolved over the years is the single-lap or tensile-shear specimen [Reemsnyder,1992]. Apart from the other factors, (such as the electrode face diameter, electrode force, poor metal fit up, too close to edge, dirty metal, weld spacing too close etc.), the three main process parameters of the RSW viz., % heat (or weld current), weld time and hold time have great significance in obtaining the sound and reliable weld. IS: 819-1957 (Indian Standard - Code of Practice for Resistance Spot Welding for Light Assemblies in Mild Steel) lists current, time, pressure, area of contact, surface condition of components as the factors which influence the characteristics of a spot weld. But it is silent on the effects of hold time and its interaction with other weld parameters.

A methodology has been developed for reliability analysis of such joints using laboratory specimens and for arriving at the optimum values of the process parameters to maximise the fatigue life. The methodology presented utilises extensively the full factorial Design of Experiment (DoE) techniques for better reliability of the results. [IS:10427(Part 1),1982] The application of the methodology is demonstrated through the details of the experiments conducted and results obtained on 1mm thick steel sheet spot welded specimens fabricated and supplied by the two Indian Automobile Manufacturing Companies as per their RSW process requirements. These companies wanted to know the effect of the hold time and also interaction of the hold time with the other weld parameters. An attempt is made to correlate the mechanical and fatigue strength with the residual stress on the nugget and HAZ areas of the RSW joints. Load life curves and Weibull hazard plots are presented for the RSW joints.

THE EXPERIMENTS PLANNED

The following experiments were planned and executed on the plain sheet as well as spot welded specimens of both the companies. The monotonic properties of the sheet materials of these companies were obtained using a procedure similar to the one elaborated in ASTM- E8M-94. The Cyclic properties of the sheet materials of these companies were obtained utilising the procedure outlined in ASTM-466-82 for R = 0.1. It was decided to plan tests on three types of spot welded specimens viz., single spot, parallel and series (both having two spots each at a centre-to-centre distance of 35 mm). Figure 1 shows these three types of spot welded specimens. The logic for these three types, is that the single spot (P type) gives the basic information, the parallel and series ones (Q and R types) are representative of the configuration including the pitch typically used by the manufacturers. Based on knowledge gained through the study of various relevant literature on the subject of the present research project and after brain storming sessions with the design and fabrication shop engineers of these two automotive vehicle manufacturing companies, details of weld parameters (or factors), which required optimisation, were selected. Table 1 shows the spot weld process parameters for the full factorial DoE for these companies. Twenty specimens of each run number of P, Q and R types of each of the two companies were separately tested for (a) Residual Stress measurement at (i) Nugget and (ii) HAZ areas by STRESS SCAN 500 C machine of M/s American Stress Technologists Inc. (USA), (b) Tensile Shear Strength measurement by JJ Lloyd Instruments Make- Universal Testing Machine of 50 kN capacity, (c) Fatigue Life on 10 Ton MTS machine, USA make. Special grips for the testing of sheet steel specimens as well as for spot welded specimens were designed and fabricated for use on the above mentioned machines.

ANALYSIS OF RESULTS

The results obtained were statistically analysed using Yates algorithm for finding the “Main Effects and Interactions” for the average and S/N values.[Kackar,1985 and Michael,1995] For obtaining S/N values Taguchi’s robust design methodology was used. The analysis showed that the optimum combination of the parameters for M/s Alpha Co. is given by the Run No. 3 (i.e. %H = 75, WT = 18 and HT = 06) , whereas for M/s Beta Co. is given by Run No. 6 (CA = 7.6, wt = 6, HT = 15). Thereafter confirmatory experiments were conducted on twenty-five specimens each of P, Q and R types for the run number 3 and 6 from M/S Alpha Co. and M/s Beta Co. respectively. After confirming that the run number 3 and 6 respectively of M/s Alpha Co. and M/s Beta Co. gives the optimum combination of the weld parameters of these companies, twenty specimens each of P, Q and R type (of these two companies) were used for finding the Load Life curves. Similarly, twenty specimens each of P, Q and R type (of these two companies) was used for Weibull plot for the road load data made available for their vehicles by these companies.The reliability parameters have been shown in table no.2 and table no.3.

TABLE 1 – FULL FACTORIAL DoE ARRAY WITH FACTORS ASSIGNED TO COLUMNS.

Run No.	DESIGN PARAMETERS (FACTORS) – UPPER AND LOWER LEVELS.					
	M/s Alpha Company Parameters			M/s Beta Company Parameters		
	% H	WT	HT	CA	WT	HT
1	75	16	06	7	6	5
2	75	16	10	7	6	15
3	75	18	06	7	11	5
4	75	18	10	7	11	15
5	80	16	06	7.6	6	5
6	80	16	10	7.6	6	15
7	80	18	06	7.6	11	5
8	80	18	10	7.6	11	15

NOTES

(1) Symbols: %H: % Heat, WT: Weld Time (Cycle), HT: Hold Time (Cycle), CA: Current Amplitude (Kilo-Ampere)

(2) The other process parameters, which were not considered for the optimisation, were kept constant during this study.

(a) M/s Alpha Co. kept Squeeze Time = 12 cycles, End of Hold Time = 5 cycles, and Off Time = 5 cycles. The 75% & 80% Heat approximately corresponds to 4.9 & 5.2 kA respectively.

(b) M/s Beta Co. Kept Squeeze Time = 15 cycles and zero cycle for End of Hold Time and Off Time, as this company has not gone for automatic repeat cycle.

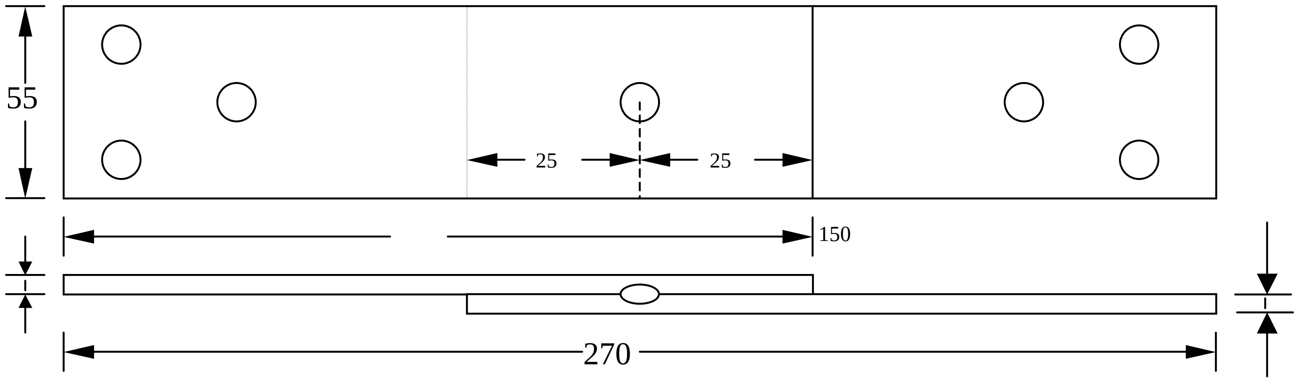
(3) All the samples were spot welded by these two companies on the spot welding machine supplied by M/s JAYHIND SCIAKY LIMITED, POONA of similar rating. Care was taken to use 1 mm-thick Automotive Grade Low Carbon Steel of almost similar chemical composition and mechanical properties, although company specific differences existed.

TABLE 2 - BASIC DESIGN DATA OBTAINED FROM THE WEIBULL PLOT OF THE OPTIMISED RSW PROCESS PARAMETERS FOR THE ROAD LOAD DATA OF M/s ALPHA Co.

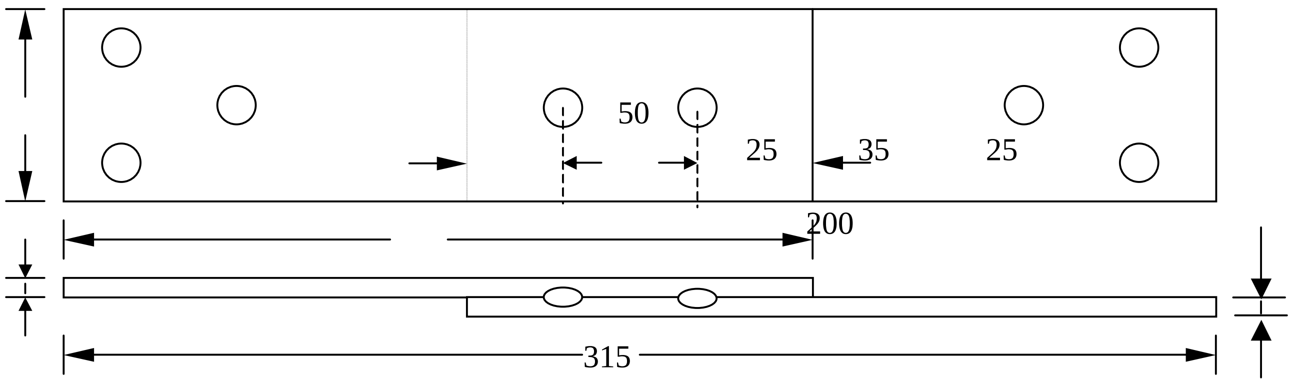
S.No.	Basic Reliability Parameters	P Type Specimen	Q Type Specimen	R Type Specimen
1	Shape Parameter = β	1.8	2.38	2.2
2	Characteristic Life = η	$4.15x10^6$	$4.65\ x10^6$	$4.45\ x10^6$
3	Percent of Component Failed at Mean life = P_μ	55.5	52.8	53.5
4	Mean life = μ	$3.65x10^6$	$4.25\ x10^6$	$3.95\ x10^6$
5	Multiplication Factor for Standard Deviation = B	0.526	0.394	0.43
6	Standard Deviation	$2.18x10^6$	$1.832\ x10^6$	$1.913\ x10^6$

TABLE 3 - BASIC DESIGN DATA OBTAINED FROM THE WEIBULL PLOT OF THE OPTIMISED RSW PROCESS PARAMETERS FOR THE ROAD LOAD DATA OF M/s BETA Co.

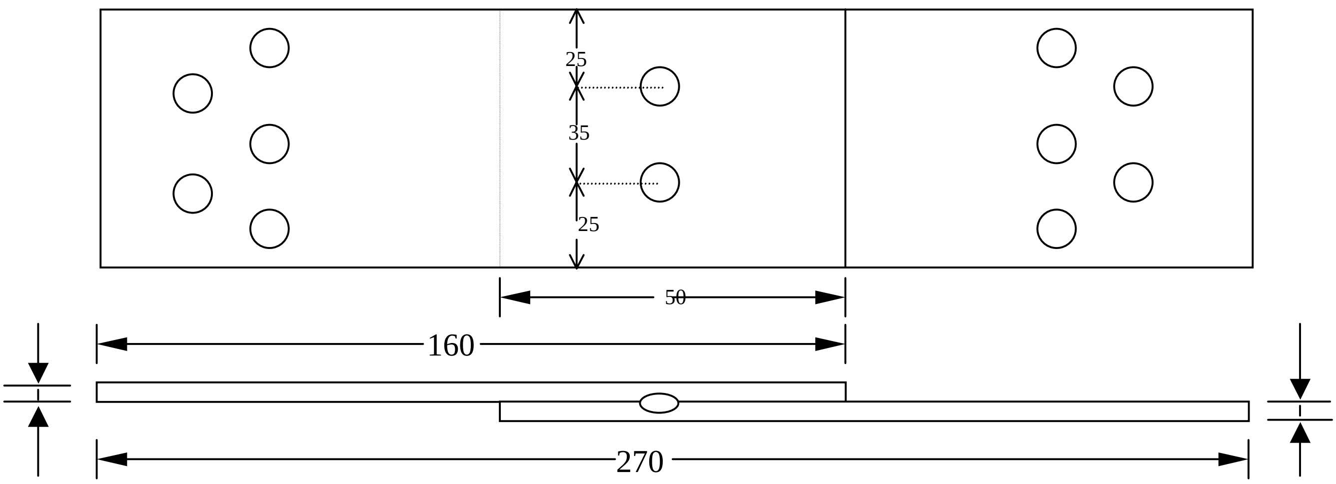
S.No.	Basic Reliability Parameters	P Type Specimen	Q Type Specimen	R Type Specimen
1	Shape Parameter = β	2.3	2.15	2.25
2	Characteristic Life = η	$4.19\ x10^6$	$5.25\ x10^6$	$4.65\ x10^6$
3	Percent of Component Failed at Mean life = P_μ	53.0	53.9	53.7
4	Mean life = μ	$3.92\ x10^6$	$4.65\ x10^6$	$4.2\ x10^6$
5	Multiplication Factor for Standard Deviation = B	0.41	0.44	0.42
6	Standard Deviation	$1.718\ x10^6$	$2.31\ x10^6$	$1.953\ x10^6$



(P) Single Spot Weld Test Specimen



(Q) Two Spot Weld Column Type Test Specimen



(R) Two Spot Weld Row Type Test Specimen

Fig 3.1 Configuration of RSW Specimen

CONCLUSION

The following are the conclusions:

1. A procedure was developed for finding out the effect and interactions of the RSW hold time with the other weld parameters utilising DoE.
2. The relation of the residual stresses on the nugget and HAZ of the spot weld with tensile shear strength and fatigue life were found out.
3. The Load Life curve and Weibull plot for the basic design configurations of the sheet metal were obtained for the optimised weld parameters.

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