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A Review on Effect of Spot Weld Parameters on Spot Weld Strength

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Abstract **- Resistance spot welding (RSW) is vastly used in automobile industries to cut weight and lower the cost. It is necessary to improve ultimate strength of spot-welded joints for safety of automotive. The Spot weld joints provide localized connection which leads to high stress concentration in the joined plates. Also due to improper design excessive stresses and premature failure occurs in joined plates. A designer should have concentration on the strength of component by introducing the changes in its geometry and weld patterns that will reduce the vibration and noise of the structural models. Also increases the strength of the structures. The optimum design of geometry and weld patterns will give optimal performance i.e. good strength to the composed structures. The aim of this study is to find out the effect of spot weld parameters on the strength of spot weld. The effect factors of multiple spot-welded joints strength are analyzed including spot weld arrangement, distance between two spot welds, spot weld diameter and thickness based on finite element analysis (FEA) and experimental results. The study shows that weld diameter and thickness are primary factors affecting the strength of the joints for a given material. On the basis of effect factor analysis the optimized parameters are also discussed to improve the strength of structure.**

Keywords **- RSW, spot weld parameters, strength, FEM**

I. INTRODUCTION

Spot Welding

Resistance spot welding (RSW) was introduced in the 1950s, and now it is widely used technique in the automotive industry. The components of vehicle like body in white, cradle, doors etc. are made from thin metal sheets that are connected with spot-welded joints or simply spot welds. In the process of creating a spot weld, two or more metal sheets are pressed together by electrodes, and an electric current is passed through them. The resistance of the metal generates heat, and the sheets are welded together by means of local metal fusion and spot weld is created. No welding material is added in this process. There are three regions in a spot weld plates. A weld nugget with cylindrical shape, a heat-affected zone (HAZ) and the base material sheets [1,2]. These regions have different material properties. For example, the yield stress in the nugget is up to three times higher than in the base material [1,3], and the plastic properties of the HAZ are non-homogeneous [4].

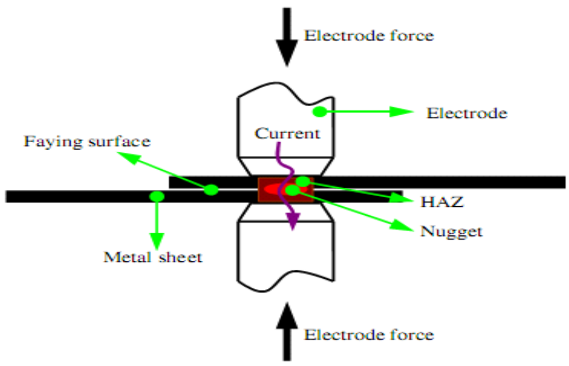


Figure 1 spot welding process - Source-[10]

Due to the applied pressure by the electrodes during the welding, the thickness of the nugget is usually less than the thickness of the two metal sheets. This nugget indentation is not significant for plate thickness up to 1 mm, but is more feasible when thick plates are assembled. When a change of thickness takes place stress the concentration may occur at the edges, which may result in crack initiation [4]. Also, the transient heating and cooling results in hardening of the material, and a pre-stress may remain after cooling.

A typical vehicle body in automobile is made of steel sheets having several thousands of spot welds. The optimal diameter and distance between two successive spot welds are determined by the sheet thickness. The diameters used in range of 3 to 7 mm, with a mean of 6 mm [1]. It is noted that the assembly process is not perfect; sometimes a few spot welds are even missing or broken right from the beginning of the vehicle life.

II. LITERATURE REVIEW

The spot weld strength is most important part in the any of the structure which is spot welded. Hence it is very much important to study the parameters which affecting the strength of spot weld. In this section the summery of previous researchers on characteristics of spot weld strength; effect factors are discussed. The previous research work describes structural investigation; finite element analysis work and experimental investigation.

The overview of some of literature is given below.

Donders S. et al [1] studied the effect of spot weld failure on dynamic vehicle performance. The impact of spot weld quality and design for vehicle functional performance also an industrial robustness study is presented that assess the effect of spot weld failure on dynamic vehicle characteristics. The FEA body in white (BIW) structure of vehicle is introduced in the study.

Zhang X. et al [2] investigated the strength of multiple spot weld joint. They also studied its automobile application i.e. vehicle chassis having many spot welds. Analyses of these structures are based on finite element study and experimental study. They have studied the finite element model for multiple spot weld joint under tensile shear load by experimental method. The effect of multiple spot weld joint strength is analyzed considering spot weld spacing, edge distance, weld size and thickness using FEA. The conclusion of this study is weld parameters like weld size and thickness are primary factors affecting the strength of the joint of materials.

Ertas A H. et al [3] studied the optimum locations of spot weld and the optimum overlapping length of joined plates. Minimum weld-to-weld and weld-to-edge distance recommended by the industry are considered as side constraints for optimum design of spot weld. The total stain life equation is used to predict the fatigue life. They suggest that number of spot welds significantly affects the strength of structure. The distance between two spot welds, arrangement of spot weld and diameter of spot welds, these are the parameters considered for optimum design of spot weld. Spot weld is studied by using FEA and under different loading conditions. They introduced penalty function to prevent the close spot welding and the boundaries of the plate, which cause effect on optimal characteristics of spot weld.

Moshayedi H.et al [4] investigated the two dimensional finite element simulation of resistance spot welding process is performed using fully coupled electrical, thermal and incrementally coupled thermal and mechanical analysis on steel sheets to predict weld nugget formation through temperature distribution at different welding cycles and current intensities. Finite element modeling is used for investigation of effect of welding current and temperature.

Nacy S.M.et al [5] investigates the study of vibration analysis of stiffened conical shell. Experimental and FEA study is performed for this investigation. The effect of conical shape stiffeners considering its stuffiness, mass, damping factor are studied in details. They described structural and modal analysis of conical shape stiffeners considering effect of spot weld.

Prasad K. et al [6] investigates the study of spot welded stiffeners. This study focuses on effect of spot weld pattern and profiles of stiffeners under the vibration analysis of structures. Both FEA and experimental study are carried out for vibration analysis of plates with spot welded stiffeners. In FEA study, modal analysis method is used to find the natural frequencies of all test structural models. Ls-Dyna and HYPERMESH software are used for FEA study.

To back up the results obtained by FEA study, experimental analysis is done to find frequencies of the same models using FFT analyzer. From the above FEA and experimental results, it is revealed that, the profile of stiffener and weld pattern having much more influence on natural frequencies of the structural model. The structures having less frequency are useful for the application where high excitation frequency and the structures having high frequency are useful for the application where less excitation frequency.

Rusinski E. et al [7] investigates briefly the effect of diameter of spot weld on structural characteristics. The strength of spot welded structures is studied under compression considering effect of diameter and pitch of spot weld. FEA study is also carried on same structures taking into account physical and geometrical nonlinearities.

The strength of spot welded structure is precisely determined under the test of compression. The information regarding structural details including all the parameters of the spot weld are referred for the study of vibration analysis of plates with spot welded stiffeners.

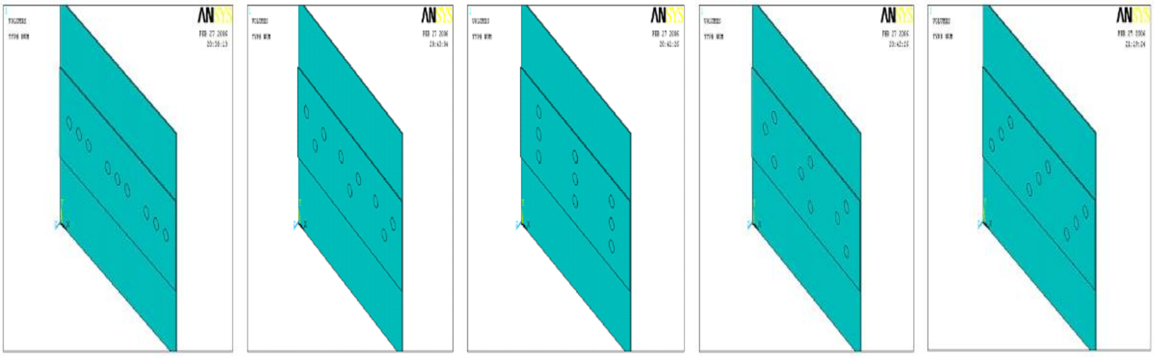
Palmonella M. et al [8] studied two types of the spot weld structures are CWELD and ACM-2. It is shown in this paper that natural frequencies of proposed structures are very sensitive. These structures are mainly useful for many sheet metal applications to optimize the design. In this paper the techniques of model updating in structural dynamics are used to analysis and to improve CWELD and ACM-2 model. Guidelines are given for the model updating and implementation mainly in application of an automotive body in white (BIW) model. It has thousands of spot welds and major influence on the structural dynamics of the whole body.

They also studied the effect of spot weld diameter on the dynamics of the spot welded sheet metal structures using FEA and experimental analysis.

III. STUDY OF PARAMETERS

A Spot Weld Arrangement

The selection of profile of plate and weld arrangement has more influence on the excitation frequency of the system in order to avoid resonance condition of the system i.e.to increase strength. For analysis a rectangular stainless steel plate with dimensions of (120mm, 100 mm, 0.6 mm) stiffened by another stainless steel plate of (120mm, 40mm, 0.6mm) in the longitudinal direction, is considered in this study [5]. Five groups of plates prepared as the stiffened plate specimens, with different spot welding arrangement illustrated in figure 2. The measurement of natural frequencies has been done with and without including the effect of residual stresses for each specimen to find the shift in this frequency due to spot welding.



(a) (b) (c) (d) (e)

Figure 2 Different spot weld position[5]

The frequency response for each stiffened plate is found out by slowly increasing the driving frequency of the vibrator with the help of the sine generator. The natural frequency is distinguished by observing the sharp increase in amplified of the pickup output, which is amplified and displayed on the oscilloscope.

Heat treatment is employed to spot weld joint to investigate their effect on the natural frequency and mode shape of stiffened plate. The stress reliving heat treatment is employed at a temperature of (750 C), for 3 minutes duration, then the weldments is cooled by air.

A.1 Experimental & FEM model

Experimental tests are designed in order to measure the natural frequency and mode shape of the plates with spot welded stiffeners. A simplified block diagram for these instruments is shown in figure 3. The sheet material used in this investigation for all tests is an austenitic stainless steel AISI 304 sheet with nominal thickness of 0.6mm.

The FEM analysis is carried out in two steps (coupled-field analysis). A non-linear transient thermal analysis is conducted to obtain the global temperature history generated during the welding process. A stress analysis is then developed with the nodal temperatures obtained from the thermal analysis, which are applied as “body force” in the subsequent stress analysis. Then by using the result from the stress analysis with pre-stress on, dynamic structural analysis is achieved. ANSYS software is used to achieve such a task. The accuracy of the FEM depends on the density of the mesh used in the analysis. Therefore, it is necessary to have a more refined mesh closer to the weld nugget, while in regions located away from weld-nugget a more coarse mesh is used, as shown in figure 4. After solving the non-linear transient heat transfer and residual stress model, modal analysis are achieved to determine the natural frequencies and mode shapes of a structure.

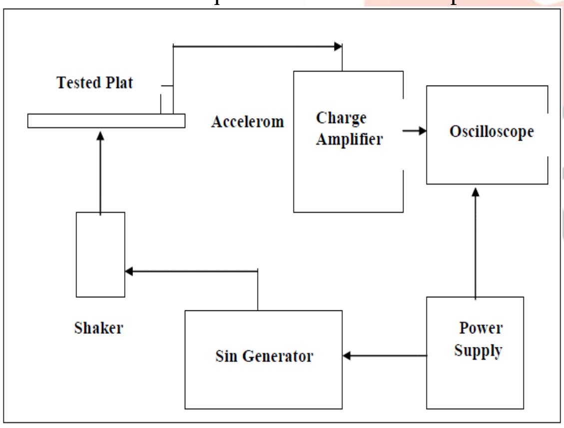


Figure 3 Block Diagram of the Experimental Setup [5]

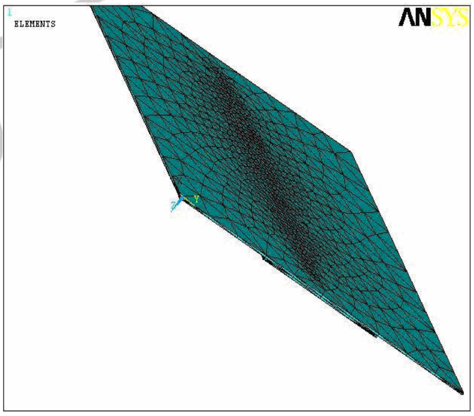


Figure 4 Finite element mesh [5]

A.2 Results and Discussions for spot weld arrangement

In order to clarify the results obtained from this study, three main effects are consider namely, spot welds distribution, residual stresses and boundary conditions. The first two natural frequencies for the five models considered in this study with a clamped-free-free-free boundary condition. Though differences are small, but it is observed that the highest natural frequency is obtained by model 5. Both numerical and experimental results shows that the inclusion of residual stresses tends to increase the natural frequency. For these stresses are mainly tensile in nature, thus increasing the lateral stiffness of the plates, leading to an increase in natural frequency. The amount of increase in natural frequency due to residual stresses is small because these stresses are acting on small areas (spots) as compared to the area of the plate.

B Distance Between Two Spot Welds

For automobile body, there are about 3000-5000 spot welds, and for a typical front sub frame, there are more than 200 spot welds. It is very important to improve spot welded joints strength so that the sub frame can endure specific loads during the automobile service life. For the above reason it is important to study the effect of distance between two spot weld on strength of spot weld [1].

It is important to improve ultimate strength of spot-welded joints for automobile safety. The finite element models (FEM) for multiple spot-welded joints under tensile-shear load are investigated based on experimental results. The effect factors of multiple spot-welded joints strength are analyzed including distance between two welds, edge distance, weld size and thickness based on finite element analysis (FEA). The analysis shows that weld size and thickness are primary factors affecting the strength of the joints for a given material.

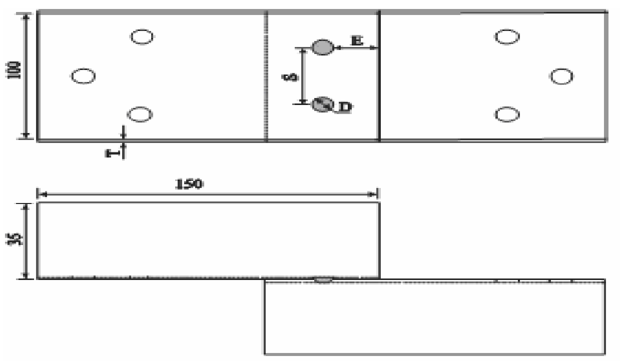


Figure 5 Cross-tension test specimen layouts [2]

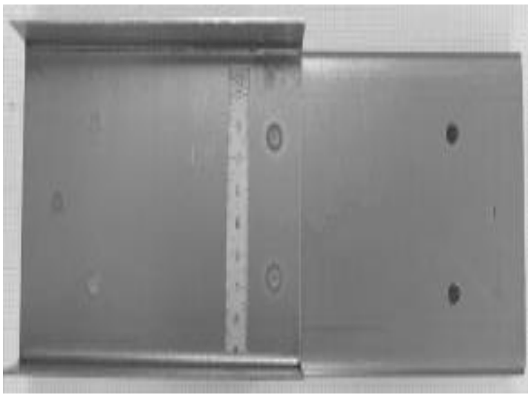


Figure 6 Tensile-shear test specimen layouts [2]

Tested specimen is made from two U-shaped channels and joined by two spot welds. The base dimensions and layout of the cross-tension specimen and tensile-shear specimen are shown in Figure 5 and Figure 6. The length of each U-channel is 150 mm, the width (flange to flange) is 100 mm, and the height is 35 mm. S represents the distance between the two spot welds, E represents the edge distance from the edge of the spot weld to the end of the U-channel, D represents the weld size, T represents the sheet thickness, as shown in Table 1.The material is DP590 which is extensively used in automobiles.

Table -1 Test specimen parameters [2]

Parameters	**S**	**E**	**D**	**T**
Dimension, mm	**44**	**11**	**7**	**1.6**

B.1 Results and Discussions for distance between two spot weld

From the results, we can conclude that failure load is affected by the distance between two welds. When the spacing becomes smaller, it shows lower failure load, which is because there is stress superposition between the two welds, the nearer the two welds, the higher the stress around the two welds.

Table-2 Spot weld distance effect on failure load under tensile-shear load [2]

	Spot weld distance, mm			
	10	**20**	**44**	**60**
Failure load, kN	**44.14**	**50.09**	**50.05**	**49.69**

From Table 2 we observe that when spot weld distance changes from 10 mm to 20 mm, the failure load is increased 13.5%. From 20 mm to 60 mm, the failure load just decreased by 0.7%. so, it is important to optimize spot weld layout to get the balance between cost and performance. Small spacing should be avoided, and 45 mm spacing is recommended.

C Spot weld diameter

The spot weld diameter is one of the significant factor determining the strength and mode of eventual fracture. Therefore to study the effect of spot weld diameter on strength is an important point.

Here the selected problems which are created from axial compression tests of thin-walled beams joined by spot welding are discussed. The specimens are subjected to fixed loading. The effect of the size of the weld's diameter and the pitch of the weld on the amount of absorbed energy is studied. A discrete model is built and FEM strength computations of the thin-walled beams considering physical and geometrical nonlinearities are performed. Thin-walled elements are the most common components of the supporting structures of vehicles, earth-moving machines and protective structures. One of the many kinds of thin-walled structures are girders (beams, pillars and thin walled profiles). Strength calculations in their case are reduced to an analysis of the structure of one or several thin walled elements joined together along common edges.

The main factors which determine impact energy absorption by the car's stringers (beams) are the shape of the thin-walled profile and the technology of its manufacture. One such type of manufacturing technology consists in joining together, by resistance spot welding, two open omega-shaped profiles made of steel characterized by very high strength and plasticity (e.g. DOCOL 800DP) to form one closed profile. Such beams are mounted in the car's front part to absorb impact energy in the case of an accident.

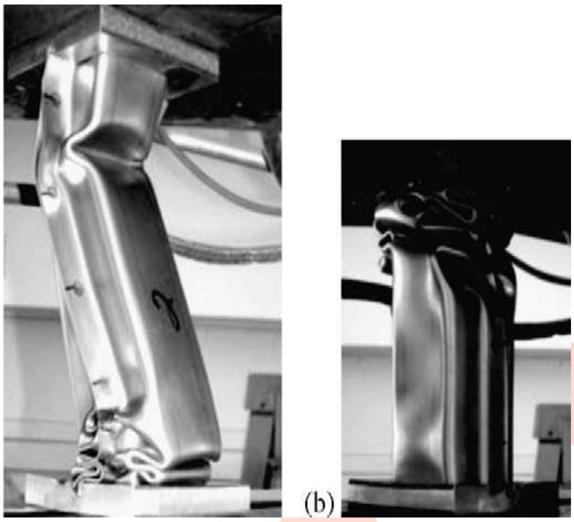
The reported results of strength tests carried out on single spot welds are not sufficient to predict the behavior of the thin-walled beams under axial compression. Considering the phenomena which occur when and after a thin-walled beam loses stability, the beam geometry, the kind of material and the geometrical and physical nonlinearities the designer must precisely design and specify the strength calculation methodology for such type of the structures.

C.1 Results of Experimental analysis

The tests have shown that crushing is more stable in the case of beams with cut corners and an over press (Fig. 7 b). A beam without such a pre-imperfection tends to buckle during crushing, performs much less deformation work and so absorbs less energy. It is observed by experiment that the absorption of energy is the largest for 8 mm-diameter spot welds spaced at every 25 m.

C .2 FEM strength analysis of thin-walled beams subjected to crushing

Discrete models of beams, of the same size as the actual beams, with clamps (one slidable, the other fixed) are built for an FEM analysis performed using the ABAQUS/Explicit system. Half of the model is used to avoid long strength calculations (Fig. 8). Numerical FEM determination of axially compressed beams joined together by spot welding is a complex calculation problem. In such calculations one must take into account the material's physical nonlinearities (an analysis of the structure after the yield point has been exceeded, large deformations in the elastoplastic range), the rubbing of the particular sheet metal folds against each other and geometric nonlinearities (the buckling of the beam) .



(a) (b)

Fig. 7 Stable crushing ensured by cutting beams corners (a) beam without cut corners after crush test, (b) beam with cut corners after crush test [7]

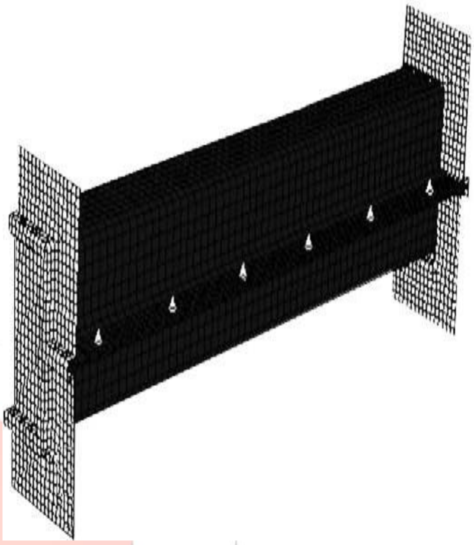


Fig.8 Discrete model of beam with clamps [7]

C.3 Results of FEM analysis

From figure 9 we can see that the energy absorption is highest for weld spacing t=25mm (as compared with the results obtained at t = 50 mm) and weld diameter d = 4 mm, but the difference in absorbed energy between d = 4 and 8mm is slight. Although energy absorption is the highest in the case of the weakest joint (d = 4 mm), the beam crushed in a more stable way at d = 8 mm.

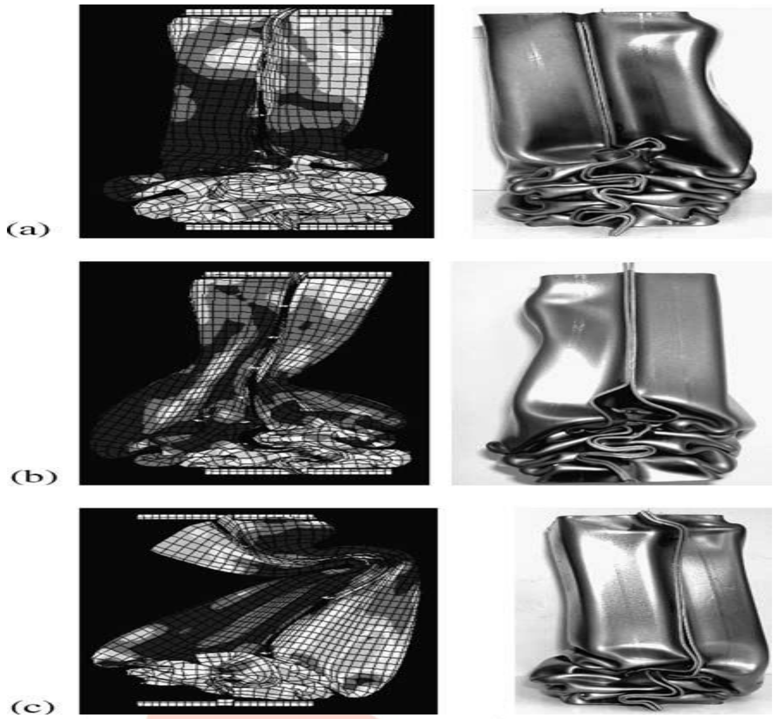


Figure 9 Comparison of beam deformation patterns obtained from numerical FEM simulations (ABAQUS) and laboratory tests: (a) d = 8 mm, t = 25mm (b) d=4mm, t = 25 mm; (c) d = 8 mm, t=50mm [7]

IV. CONCLUSION

In this review we observed that the parameters affecting the strength of multiple spot-welded joints strength are spot weld arrangement, distance between two spot welds, and spot weld diameter.

For spot weld arrangement highest natural frequency is gained by model 5 for C-F-F-F boundary condition.

As the distance between two spot welds decreases, the failure load also decreases, since there is stress superposition between the two welds. The nearer the two spot welds, higher the stress around the two welds. Small spacing should be avoided, and 45 mm spacing is recommended.

The absorption of energy is the largest for 8 mm-diameter spot welds spaced at every 25 mm. The spot welds withstand much better shearing forces than normal forces.

Also the spot weld can rupture in two modes. Nugget pullout failure which occurs in larger (stronger) joints and interfacial failure occurs in smaller (weaker) joints.

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