Spot Weld Fatigue Life Prediction by Using Multiaxial Fatigue Criteria's

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Abstract - **In this study, Tailgate (vehicle back door) side hinges systems with the spare wheel condition are considered. When the spare wheel is mounting on tailgate then spare wheel load need to transmit inside body panel because of door sag problem. The spare wheel load transmitted to body panel by reinforcement to hinges and hinges to body panels. In reinforcement system reinforcement panels, brackets are connected to the inner panel by spot welds. In all reinforcement system spot weld is a critical element for static and fatigue failure so it is needed to carefully design for optimum position. In this study, the effects of weld arrangement on the static and fatigue behaviour of the multi-spot welded joints have been investigated. Spot weld pitch, spot weld size and spot weld to trim edge distance suggested by industries are considered. In the simulation part, Tailgate consider as symmetry about carline along Z- axis direction. In half section the number of area are consider and number of possible spot weld arrangement for this areas are tested by finite element analysis by using software ANSYS. Fatigue life calculation is done by using multiaxial fatigue criteria. Four sets of spot weld arrangement are used for evaluation. As per results it is observed that the spot welded arrangement effect has a considerable role in fatigue strength of multi-spot welded joints.**

Index Terms - **Fatigue life, Finite element analysis, Resistance spot welding, Tailgate.**

I. INTRODUCTION

Tailgate means the back door of the SUV (sport utility vehicle). The tailgate is mainly classified into three types as per the opening, 1) top opening 2) side opening 3) bottom opening. In our project side opening with spare wheel condition are consider as shown in fig.1. Spare wheel are mounted on tailgate like Tata Sumo, Tata Safari and Mahindra Quanto. There are two advantages, easy removal and mounting of spare wheel and aesthetic look some time prefer by styling department. When spare wheel mounted on tailgate all load of spare wheel is need to transmit into body for door sag problem. The spare wheel load transmission takes place through reinforcement (sheet metal brackets) to hinges and hinges to body panels.

Fig.1. Eco sport vehicle tailgate with spare wheel

Tailgate system contain inner panel, outer panel, hinge reinforcement, latch reinforcement, and dovetail reinforcement used in regular structure. When spare wheel added on tailgate the middle reinforcement structure added in above mention structure. All reinforcement and panels are connected to each other by spot weld. As per literature survey the spot weld is the most critical element to static and fatigue failure. In our project 26 kg spare wheel is overhang and in vehicle moving condition always cyclic loading acting on to spot weld system so it is need to be carefully designed. When one of the spot welds fails inside tailgate the harsh nose propagation it is very irritating to customer also it is not reparable so need to replace door. Tailgate system is shown in fig.2.

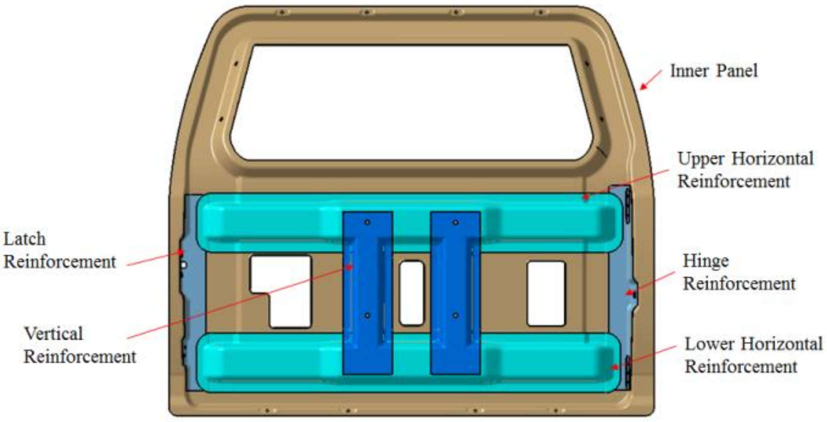


Fig.2. Tailgate system

Inner panel is providing the connection between hinges and latch and also support to outer panel. Outer panel is aesthetic look of the vehicle aligning with inner panel by hemming. Hinge reinforcement is used for strengthening the hinge side because it takes all load of overhang portion of door. Latch reinforcement used for strengthening the latch side because repetitive opening and closing action of door. Middle reinforcement structure is used when spare wheel is mounted on tailgate and used as load transmitting element to the hinges and latch.

All reinforcement is attached to one another by resistance spot weld (RSW). It is possible to design various spot weld position but for maximum static and fatigue strength need to design the optimum position of the spot welds.

In this project, positions of spot welds are considered as design parameter to maximize the static and fatigue life. Sheet thickness and material are assumed to be predetermined according to the strength requirements of the structure. Minimum weld to weld and weld to edge distances recommended by the industry are considered. Spot weld diameter 5mm for two panel spot welding and 6mm diameter for three metal spot weld are consider.

It should be noted that processing parameters like welding current, welding time, clamping force, electrode diameter, hold time and process conditions like clamping conditions, welding sequence have significant effect on the quality of the spot-weld joint in terms of fatigue strength and geometric distortions. In order to ensure the integrity of the joint, one should therefore consider these factors. However, the present study focuses only on the position of the spot welds; optimum selection of processing parameters is outside the scope of this study.

II. LITERATURE REVIEW

Various researchers work regarding the spot weld static and fatigue strength are discussed below,

Ahmet H. Ertasand and Fazıl O. Sonmez [1] discussed about the fatigue life of the spot weld. Total strain life equation, Coffin-Manson equation by including the effect of elastic strain, yielded was used. As per conclusion fatigue life of spot welded joints depends on the stress and strain states around the spot welds.

Ahmet H. Ertasand and Fazıl O. Sonmez [2] discussed variables for spot weld like sheet thickness, spot weld nugget diameter, number of spot welds and how it affecting the fatigue life of spot-weld joints has been investigated. As per research conclusion a larger number of small spot welds proved to be more effective in increasing fatigue strength in comparison to large spots having the same cross sectional area.

M.M. Rahman et al. [3] was discussed the effect of the spot weld diameter and sheets thickness on the fatigue life of the of the spot weld joints. They are observed from result, the fatigue life of the structure increases with the increases of the spot weld diameter and thickness of the sheet.

R.S Florea et al. [4] were discussed fatigue behavior in spot welded specimen with the influence of the process parameter. As per the research no fatigue initiation sites were observed in the porous area formed from rapid solidification in the center of the welds, all fatigue initiation sites were experienced at the outside in the welding button. Brittle failure occurred through the center of the weld area at the end of specimen life.

Hong-Tae Kang et al. [5] discussed the fatigue characteristics of spot welds for three equal thickness sheet stack-ups of a Dual Phase (DP600) welded to itself under tensile shear loading. The experiments were designed to investigate the effects of electrode tip geometries, surface indentation levels, and base metal strengths on fatigue life of the tensile shear spot welds. As per conclusion the effect of surface indentation levels on fatigue strength of spot welds was negligible.

Ryota Tanegashima et al. [6] conducted three dimensional observation of the fatigue crack propagation in the spot welded joints using the high strength steel for fatigue characteristics. As this result, their fatigue crack indicated almost the same behaviour as constant stress samples.

A. Krasovskyy et al. [7] presents a mechanism based approach for lifetime prediction of welded joints, subjected to a multiaxial non proportional loading. The stage of a fatigue crack initiation becomes insignificant and the threshold for the initial crack propagation can be taken as a criterion for very high cycle fatigue (VHCF) whereas crack growth analysis can be used for low and high cycle fatigue (LCF, HCF). As per conclusion welding process simulation, thermo physical material modeling and fracture mechanics, considers the most important aspects for fatigue of welds.

S. k. Khanna et al. [8] presented pertains to fatigue testing, fatigue life modeling and prediction, and fatigue-related fracture. Fatigue testing and life and failure mechanisms of spot welded joints are reported for most modern steels such as mild steel, high strength low alloy steels, dual phase steels and transformation-induced plasticity steels. The effect of fatigue test coupon types and loading conditions are also discussed.

Tomoyuki Fujii et al. [9] carried out the fatigue tests on spot welded and spot weld-bonded joints of mild steel and ultra-high strength steel plates. As per the discussion the fatigue strength of the spot weld-bonded joints is higher than that of the spot welded joints because debonding initiates from the edge of the adhesive bonding, and propagates to the spot weld nugget. The fatigue strength is improved because the stress concentration of the nugget edge is considerably reduced in large part of fatigue life.

Yuh J. Chao [10] was discussed the failure mechanisms of spot weld in lap shear and cross tension test samples. As per the result while the lap shear sample is subjected to shear load at the structural level the failure mechanism at the spot weld is tensile mode.

Ahmet H. Ertas et al. [11] conducted a series of experiments to study the fatigue failure of spot-welded modified tensile-shear specimens made of low carbon steel. In the numerical part of this study, a finite element analysis was carried out using commercial software, ANSYS, to determine the stress and strain states within the specimens. Based on the predicted stress and strain states, fatigue analyses were performed using several models for life assessment. Then, the measured and predicted fatigue lives were compared, and the suitability of the models was discussed. Among the strain-based models, Coffin–Manson and Morrow’s means stress models yielded the best predictions.

J.H. Song et al. [12] propose an accurate failure criterion of spot welds under combined axial and shear loading condition. Test fixtures and a specimen were designed with the aid of information from finite element analysis results in order to obtain the failure load of a spot weld under the combined load with the constant ratio of the shear load to the axial load. It was found that the failure criterion proposed provides a fairly accurate description of the failure load obtained from experiments under combined axial and shear loading conditions.

Fengxiang Xu et al. [13] explore the failure incidence of resistance spot welding in dual-phase lap-shear specimens. The stress function approach is adopted to derive an analytical solution to a lap-shear specimen containing a spot weld nugget subjected to the uniformly distributed loading condition, which provides stress distributions near the spot weld nugget.

Ryota Tanegashima et al. [14] investigated the fatigue fracture mechanism in spot welded joints using a 590 MPa-class base metal, fatigue tests were conducted under constant loading conditions. In this study, three dimensional observations were made on the propagation behavior of fatigue cracks initiating at the edge of the slit between sheets. Moreover, an evaluation method of the fatigue life was proposed for random loading conditions.

B. Wang et al. [15] conducted micro-hardness tests, tensile and fatigue tests of spot welded Q&P980 steel were performed using tensile-shear and cross-tension specimens. The hardness values of nugget and base material were measured and it is found that the fatigue cracks in heat affected zone (HAZ) initiate at the interface between two sheets. As per the testing samples the fatigue failure modes consist of the fracture along the circumference or along the direction of width for tensile-shear specimens and pullout or fracture along the direction of width for cross-tension specimens. It is also found that the fatigue properties of spot welded Q&P980 and DP780 specimens are approximately the same in the case of tensile-shear and cross-tension specimens.

Wei-Jen Lai et al. [16] investigated the failure modes and fatigue behaviors of ultrasonic spot welds in lap-shear specimens of magnesium AZ31B-H24 and hot-dipped-galvanized mild steel sheets with and without adhesive. As per tested samples the spot welded specimens failed from the kinked crack growth mode. The adhesive-bonded specimens failed from the cohesive failure through the adhesive and the kinked crack growth through the magnesium sheet.

Ding Min et al. [17] discuss the mechanical properties of ferrite steel resistance spot welds during quasi-static tensile test. The mechanical properties are described in terms of peak load. It was shown that the fusion zone size is the most important. The failure mechanism of resistance spot welds during tensile test was studied with the aid of thermography. As per the conclusion tensile property of the spot welding specimens can be related to their microstructures. Fine-grains provide strength and coarse-grains improve uniform- elongation.

F. Esmaeili et al. [18] discussed the effects of weld arrangement on the fatigue behavior of the multi-spot welded joints have been investigated via experimental and multiaxial fatigue analysis. It was found that the SWT and Crossland criteria have the best accuracy for all types of the specimens among the applied criteria.

Tomasz Sadowski et al. [19] discuss the spot welding adhesive joints response. The whole uniaxial deformation process of samples was experimentally investigated with the application of 2 Digital Image correlation systems to monitor the development of deformation up to the final failure. Experimental result shows, the load capacity of the hybrid joints is more than 2 times higher in comparison with pure spot-welded joints and the energy absorption of the hybrid joints is 6 times higher in comparison with the spot-welded joints.

Soran Hassanifard et al. [20] discuss the effects of residual stresses have been investigated on the fatigue life of the joints. The results show that, with increasing the electrode force, the gap values between sheet joints increase and the welding residual stresses at whole nugget regions reduce with increasing the electrode clamping force level.

Jamasri et al. [21] discuss the corrosion fatigue behavior of resistance spot welded dissimilar metals with significant difference in thickness between carbon steel and austenitic stainless steel. As per the conclusion the hydrogen enhance plasticity mechanism having bigger role on the corrosion fatigue strength weakening than pitting corrosion mechanism because pitting does not appear on the spot weld surface.

Soran Hassanifard et al. [22] the effects of friction stir spot weld arrangements as multi type on fatigue behavior of friction stir spot welded joints is investigated. Using the local stress and strain calculated with finite element analysis, fatigue lives of specimens were predicted with Morrow, modified Morrow and SWT damage equations.

In above literature review discusses the static and fatigue life of the spot weld and various parameters which are affecting on them. As per above discussion the maximum research are done on the spot weld parameters but actually on the shop floor it is very difficult to control it and operators are not ready to change the setting every time. So in my project focus on the position of the spot weld which one very well controls by full proofing design.

III. SPOT WELD MULTIAXIAL FATIGUE CRITERIA'S

Many engineering components such as automotive bodies and aircraft structures are subjected to complex states of stress. The complex stress states in which the two or three principal stresses are proportional or non-proportional often occur at geometric discontinuities like notches or joints connections. The fatigue phenomenon under these conditions, termed as multiaxial fatigue, is an important design consideration for a reliable operation and optimization of many engineering components. In this investigation, to predict the fatigue life of multi spot welded joints with different arrangement, two multiaxial fatigue criteria, i.e., SWT and KBM were considered.

- Smith–Watson–Topper (SWT)

Smith et al. proposed an experimental damage parameter which is evaluated at the plane of maximum normal strain. The SWT multiaxial fatigue model is expressed as

$$\sigma_n^{max}\frac{\Delta\varepsilon_1}{2} = \frac{(\acute{\sigma}_f)^2}{E}(2N_f)^{2b} + \acute{\sigma}_f\acute{\varepsilon}_f(2N_f)^{b+c} \qquad (1)$$

In the above equation σ_n^{max} and $\Delta\varepsilon_1$ are the maximum normal stress and the maximum principal strain range at the critical plane. In this paper the maximum value of the product, $\left(\sigma_n^{max}\frac{\Delta\varepsilon_1}{2}\right)$ in any node has been used. To do so, σ_n^{max} (maximum normal stress) and $\Delta\varepsilon_1$ (first principal strain range) have been calculated during cyclic loading in any node of the FE models and consequently the maximum amount of the product of these two parameters has been employed in the Eq. (1) to calculate the estimated fatigue life.

- Kandil, Brown and Miller (KBM)

KBM multiaxial theory is based on a physical interpretation of mechanisms of fatigue crack growth. The general form of KBM parameter is expressed as,

$$\frac{\Delta\gamma_{max}}{2} + S_k\Delta\varepsilon_n = \frac{\acute{\sigma}_f}{E}(2N_f)^b + \acute{\varepsilon}_f(2N_f)^c \qquad (2)$$

The critical plane of this parameter is the plane of maximum shear strain, where $\Delta\gamma_{max}$ the maximum is shear strain range and $\Delta\varepsilon_n$ is the corresponding normal strain range at the critical plane, S_k is a material dependent constant. These values can be determined with principal stresses and strains obtained from the finite element analysis, and therefore, using the Eqs. (3) and (4) for the critical nodes near the nugget root. In Eqs. (3) and (4), $\varepsilon_1$and ε_2, are the first and third principal strains respectively. In addition, θ_1 and θ_2 in these equations are indicating loading and unloading of a cycle. These parameters were determined for every node and the maximum value of the left hand side of Eq. (2) was used to predict the fatigue life of the specimens.

$$\frac{\Delta\gamma}{2} = \left(\frac{\varepsilon_1-\varepsilon_3}{2}\right)_{\theta_1} - \left(\frac{\varepsilon_1-\varepsilon_3}{2}\right)_{\theta_2} \qquad (3)$$

$$\frac{\Delta\varepsilon_n}{2} = \left(\frac{\varepsilon_1+\varepsilon_3}{2}\right)_{\theta_1} - \left(\frac{\varepsilon_1+\varepsilon_3}{2}\right)_{\theta_2} \qquad (4)$$

IV. PROCEDURE

The tailgate structure is so large so divided it into various sections as per the joining and checking the behaviour of the spot weld by applying the positioned load. The areas selected for analysing the spot weld in tailgate system shown in fig.3 by considering symmetry about Z- axis considers only one side sections. Three areas are considered for checking fatigue strength of the spot weld. In selected area we need to check the availability of the spot weld placing area so taking the sections at each area as shown in fig.4. The sections at the selected area are shown in fig. 5.

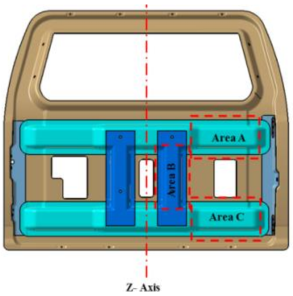


Fig.3. Tailgate areas for spot weld checking

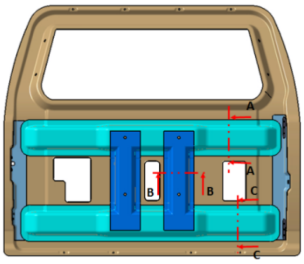


Fig.4. Tailgate sections for spot weld placing position

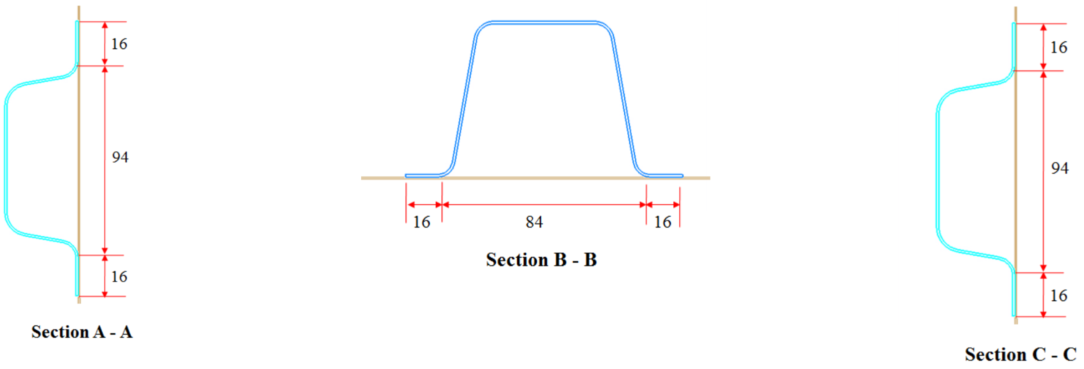


Fig.5. Tailgate sections

Section A–A is taken at area A. In section A-A two side16 mm resting flange horizontally available for spot weld placing position. So there is two type of spot weld position are possible, shown in fig.6 and fig.7.

Section B–B is taken at area B. In section B-B two side16 mm resting flange vertically available for spot weld placing position. So considering section two type of spot weld placing arrangements is possible, shown in fig.8 and fig.9.

Section C-C is the same case of section A-A. The distance between spot welds and force acting direction also same. So need not to calculate separately for section C-C.

For simulation simplicity we consider the simple plate with same distances, similar load and same spot weld position for analyse the structure.

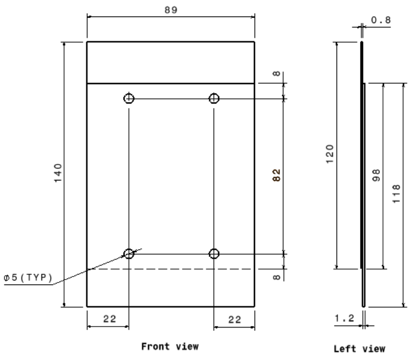


Fig.6 Type A spot weld position at section A-A

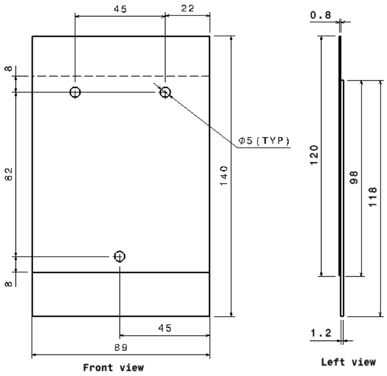


Fig.7 Type B spot weld position at section A-A

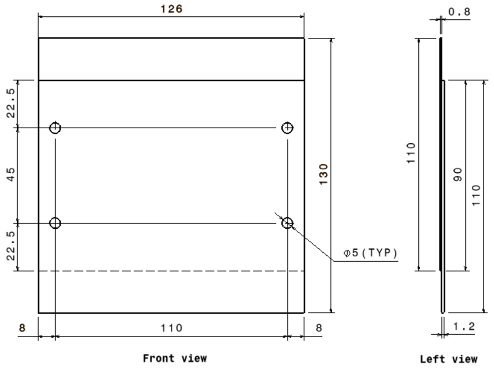


Fig.8 Type C spot weld position at section B-B

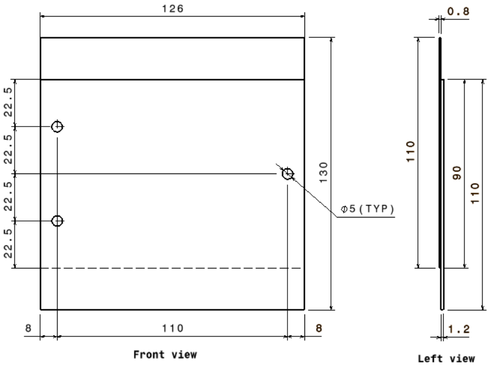


Fig.9 Type D spot weld position at section B-B

V. FINITE ELEMENT ANALYSIS

As mentioned previously, in order to estimate the fatigue strength of RSW joints, the distribution of stress and strain should be obtained near the nugget root, and finally, the number of cycles to failure can be calculated from selected multiaxial fatigue criteria. As per the discussion of static and fatigue strength calculation static strength calculate by applying load on lower sheet and fix upper sheet. For calculating fatigue life applying cyclic load by fixing upper sheet for all pattern and find out the stress and strain distribution near the nugget root and then calculate the number of cycles to failure. For this purpose, a 3D finite element analysis was performed by means of ANSYS finite element code in order to obtain the stress and strain distribution in joint sheets. In analysis 181 shell element are used for both plates and 188 beam are defined for spot weld. In present study IFHS440 material are used. IFHS440 material properties are mention in table 1.

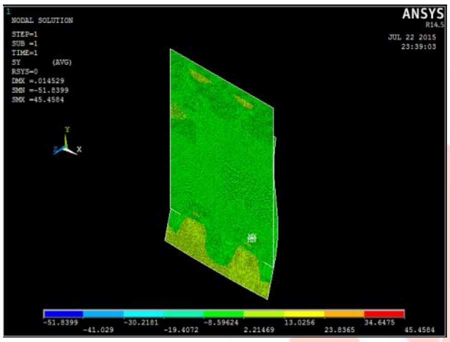
Inner panel is fixing with hinges and latch so it is consider as fix having 0.8 mm thickness panel. Reinforcement is having 1.2 mm thickness and taking a load of spare wheel in downward direction. Boundary condition for Ansys is 0.8 mm plate is fix and 1.2 mm plate is the load carrying plate.

Load acting along the downward direction in static condition is 26 kg and in moving condition nearly about peak load is 100 kg. So cyclic load varying from 250N to 1000N is considered.

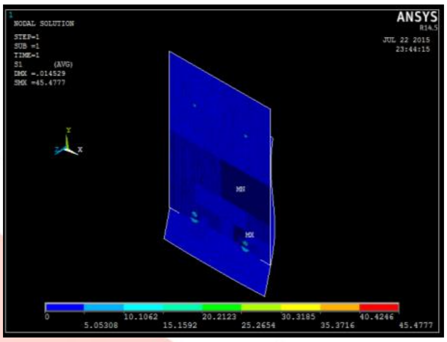
Table 1 Tensile properties and strain life parameters of IFHS440 material

Parameter	ϑ	E (GPa)	$\acute{\sigma}_f$ (MPa)	b	$\acute{\varepsilon}_f$	c	$\acute{\gamma}_f$	$\acute{\tau}_f$ (MPa)	$\acute{b}$	$\acute{c}$
Value	0.3	210	480	-0.11	0.45	-0.57	0.779	440	-0.11	-0.57

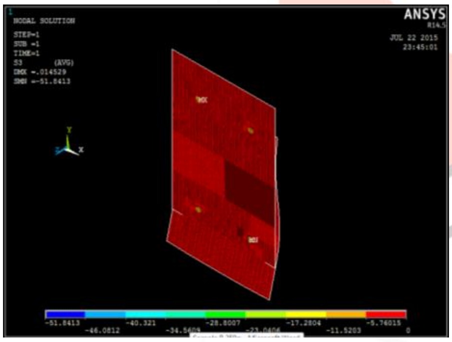
The results for type A spot weld sample at 250N load are shown in below figures.



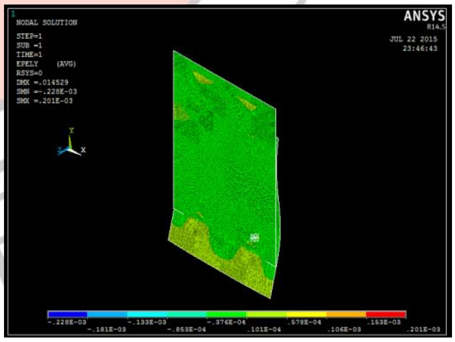
Normal stress in type A spot weld sample at 250N load



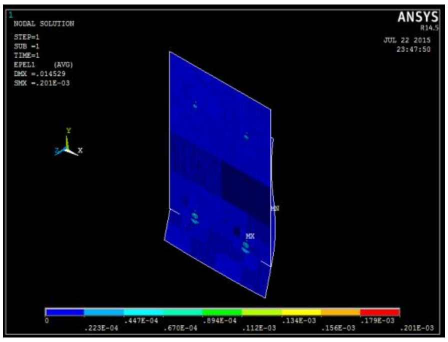
First principal stress in type A spot weld sample at 250N load



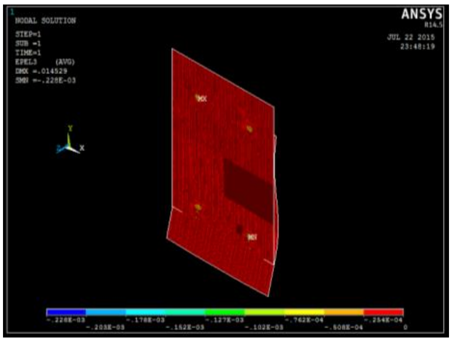
Third principal stress in type A spot weld sample at 250N load



Normal strain in type A spot weld sample at 250N load



First principal strain in type A spot weld sample at 250N load



Third principal strain in type A spot weld sample at 250N load

Fig.11. Type A spot weld pattern result at 250N load

The longitudinal stress distributions, for the four types of specimens under a typical maximum stress, strain, first principal stress, third principal stress, first principal strain and third principal strain have been collect from ansys at critical spot weld position. Four spot weld position pattern stress and strains data plotted in below table 2.

Table 2 Recorded data from analysis result

Sample	**Load**	**Normal stress (MPa)**	**First principal stress (MPa)**	**Third principal stress (MPa)**	**Normal strain**	**First principal strain**	**Third principal strain**
A	250 N	17	15	11	0.5×10^{-4}	0.5×10^{-4}	0.44×10^{-4}
A	1000 N	53	45	40	0.23×10^{-3}	0.29×10^{-3}	0.2×10^{-3}
B	250 N	17	18	15	0.3×10^{-4}	0.5×10^{-4}	0.25×10^{-4}
B	1000 N	59	51	40	0.28×10^{-3}	0.3×10^{-3}	0.22×10^{-3}
C	250 N	13	14.5	10	0.53×10^{-4}	0.69×10^{-3}	0.44×10^{-4}
C	1000 N	61	64	41	0.25×10^{-3}	0.3×10^{-3}	0.17×10^{-3}
D	250 N	20	22	17	0.13×10^{-3}	0.15×10^{-3}	0.85×10^{-4}
D	1000 N	63.5	67	46	0.32×10^{-3}	0.4×10^{-3}	0.207×10^{-3}

Sample A calculation

SWT Criteria:

$$\sigma_n^{max}\frac{\Delta\varepsilon_1}{2} = \frac{(\acute{\sigma}_f)^2}{E}(2N_f)^{2b} + \acute{\sigma}_f\acute{\varepsilon}_f(2N_f)^{b+c}$$

$$\sigma_n^{max}\frac{\Delta\varepsilon_1}{2} = 1.097(2N_f)^{-0.22} + 192(2N_f)^{-0.68}$$

$\underline{N_f = 7.256 \times 10^9}$

Where,

σ_n^{max} (Maximum normal stress) = 53

$\Delta\varepsilon_1$ (First principal strain range) = 2.4×10^{-4}

KBM Criteria:

$$\frac{\Delta\gamma_{max}}{2} + S_k\Delta\varepsilon_n = \frac{\acute{\sigma}_f}{E}(2N_f)^b + \acute{\varepsilon}_f(2N_f)^c$$

$$\frac{\Delta\gamma_{max}}{2} + S_k\Delta\varepsilon_n = 2.28 \times 10^{-3}(2N_f)^{-0.11} + 0.4(2N_f)^{-0.57}$$

$\underline{N_f = 9.25917 \times 10^9}$

Where,

$$\frac{\Delta\gamma}{2} = \left(\frac{\varepsilon_1-\varepsilon_3}{2}\right)_{\theta_1} - \left(\frac{\varepsilon_1-\varepsilon_3}{2}\right)_{\theta_2}$$

$$\frac{\Delta\gamma}{2} = 4.2 \times 10^{-5}$$

$$\frac{\Delta\varepsilon_n}{2} = \left(\frac{\varepsilon_1+\varepsilon_3}{2}\right)_{\theta_1} - \left(\frac{\varepsilon_1+\varepsilon_3}{2}\right)_{\theta_2}$$

$$\frac{\Delta\varepsilon_n}{2} = 2.13 \times 10^{-4}$$

VI. RESULT AND DISCUSSION

Spot welded tensile shear specimens with four different arrangements were produced for this investigation. It was shown that the arrangement effect has a considerable role in fatigue strength of multi-spot welded joints. In addition, finite element analysis was used to obtain the stress distribution in the RSW joints due to longitudinal applied loads in order to estimate the fatigue lives based on SWT and KBM multiaxial fatigue criteria. The multiaxial fatigue criteria are generally based on the fatigue crack initiation stage and they do not include the fatigue crack growth stage. In other words, the multiaxial criteria use only the stress and strains in critical region and they do not consider fatigue crack growth.

The fatigue life calculated from analysis result obtains from ansys. SWT criteria refer the maximum normal stress and first principal strain range for fatigue life calculation. KBM criteria refer the principal strain at loading and unloading condition for fatigue life calculation. The fatigue life for all four samples calculated from ansys result is shown in below table.

Table 3 Fatigue life for all patterns

Sr. No.	**Fatigue Criteria**	**Fatigue Life**			
		Top Horizontal Area		**Middle Vertical Area**	
		Pattern A Fatigue Life	**Pattern B Fatigue Life**	**Pattern C Fatigue Life**	**Pattern D Fatigue Life**
1	Smith–Watson–Topper (SWT)	$7.256 \text{ x } 10^{9}$	$3.8326 \text{ x } 10^{9}$	$4.801 \text{ x } 10^{9}$	$2.7935 \text{ x } 10^{9}$
2	Kandil, Brown and Miller (KBM)	$9.259 \text{ x } 10^{9}$	$4.3919 \text{ x } 10^{9}$	$6.138 \text{ x } 10^{9}$	$4.421 \text{ x } 10^{9}$

Sample A and B are suitable at top horizontal area and Sample B and C are suitable at middle vertical area. So comparison is need to done between type A and type B pattern. Second comparison is between type C and type D pattern. It can be seen from table 5 that for Type A spot weld pattern is having a more life as compared to type B spot weld pattern in both SWT and KBM criteria's. Type A spot weld pattern provide nearly two times greater life than B type spot weld pattern so type A spot weld pattern is the most preferable at upper horizontal area.

In type C and type D spot weld pattern, type C spot weld pattern is having more life as compared to type D spot weld pattern. As per KBM criteria's type C spot weld pattern is nearly 2.1 times greater life as compared to type D spot weld pattern. When KBM criteria's are used then type C spot weld pattern is having 1.4 times greater life as compared to type D spot weld pattern. In KBM criteria's are high sensitive against input because the strain obtain is very low at the root of the nugget and result also large changes with small change in input. As per result of SWT and KBM criteria's for type C and type D spot weld pattern, type C spot weld pattern is the most preferable pattern for middle vertical area.

For finding critical area in the tailgate for the spot weld is evaluated by comparing the selected areas. In selected two areas for upper horizontal area type A spot weld pattern and for middle vertical area type C spot weld pattern is most preferable. When we compare these two areas upper horizontal area (i.e. type A spot weld pattern) is having 1.5 times more life as compared to middle vertical area (i.e type C spot weld pattern)

VII. CONCLUSION

The present study was analysing the fatigue behaviour of multi spot welded joints and their arrangement effects on fatigue life. The predicted lives of four different arrangements were evaluated by employing the two damage equations; SWT and KBM. The finite element method has been used to detect the critical locations and determine the values of necessary equivalent stresses and strains. The following conclusions have been drawn:

- It was revealed that the spot welded arrangement effect has a considerable role in fatigue strength of multi-spot welded joints.
- Among the applied criteria, the SWT criterion has the best accuracy for all types of the specimens because KBM criteria is based upon strain parameter and strain induced is very low so compared high variation in the result.
- In top horizontal area out of two spot weld position pattern (i.e. A and B), A spot weld pattern provide 1.89 times greater life than B spot weld pattern.
- In middle vertical area out of two spot weld position pattern (i.e. C and D), C spot weld pattern provide 2.1 times greater life than D spot weld pattern.
- When compare two selected areas with best suitable pattern, upper horizontal area (i.e. type A spot weld pattern) is having 1.5 times more life as compared to middle vertical area (i.e. type C spot weld pattern).
- Type D spot weld position pattern is more critical for fatigue strength point of view in all tailgate areas.

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