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Static and Fatigue Performance of Resistance Spot Welds in Tailgate

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ABSTRACT

In this study, Tailgate (vehicle back door) side hinges systems with spare wheel condition are considered. It is required to transmit all spare wheel loads to hinges and latch by using reinforcement. In reinforcement system reinforcement panels, brackets are connected to inner panel by spot welds. In all reinforcement system spot weld is a critical element for static and fatigue failure so it is need to carefully design for optimum position. 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 arrangement for this areas are tested by finite element analysis by using software ANSYS. In this paper, the effects of weld arrangement on the static and fatigue behavior of the multi-spot welded joints have been investigated. In static strength calculation lap shear sample are check. Fatigue life calculation is done by using stress, strain and multiaxial fatigue criteria. For this purpose four sets of spot weld arrangement are used.

Keywords— Fatigue life, Finite element analysis, Resistance spot welding, Tailgate.

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I. INTRODUCTION

Tailgate means the back door of the SUV (sport utility vehicle). The tailgate is mainly divided 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. 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 transmitted to hinges and hinges through body. Spare wheel to hinges load transmission takes place through reinforcement (sheet metal brackets).

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.

The reason behind the selection of the subject is observation find that after certain period of time (i.e. 10 to 12 years) user are remove the spare wheel from the tailgate just because the harsh noise. In old passenger traveling SUV spare wheel are in the last seating compartment which is uncomfortable for seating the passenger. Harsh noise creation observed due to failure of the spot weld inside tailgate and two panels are continuous brushing over each other, so need to take care when design the tailgate spot weld system.

Tailgate system nomenclature is shown in fig. 1.

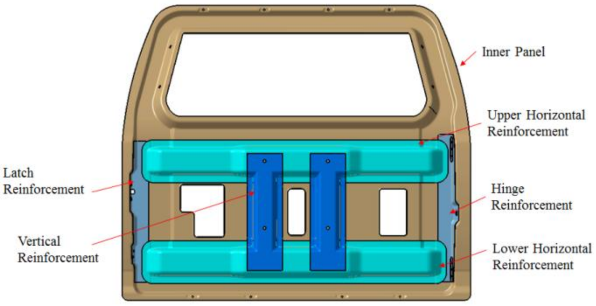

Fig.1 Tailgate system

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 spot weld. 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.

II. LITERATURE REVIEW

Literature review regarding the static and fatigue strength are as follows,

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.

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.

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.

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.

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.

III. STATIC AND FATIGUE STRENGTH

Resistance spot weld is the most critical element in all structure so it is need to be check for static and fatigue life.

A. Static Strength

In this study spare wheel is mounted on tailgate so static load acting on the reinforcement in vehicle stationary condition. Some times occupant may stand on the spare wheel for taking luggage from carrier this one condition also take into consideration. In static loading condition all load acting as longitudinal direction downward and shear load acting on the spot weld. Failure of spot weld is related to many parameters contains residual stress, welding parameters, thickness, nugget size, and material properties of the HAZ and the base metal.

1) Lap Shear Sample: For lap shear samples, since the failure is predominantly by uni axial tensile load and the weld nugget is circular, a harmonic tensile stress distribution around the weld nugget, as shown in Fig.2.

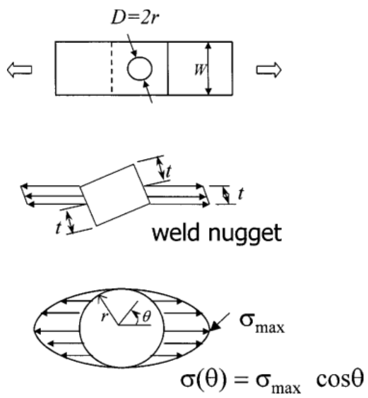

Fig.2 Assumed stress distribution around the weld nugget in a lap-shear sample [10]

The distribution of the stress can be written as,

$$\sigma(\theta) = \sigma_{max} \cos\theta \quad (1)$$

Where, θ= - 90^0 to 90^0 and σ_{max} is the maximum tensile stress occurring at θ= 0^0. Due to symmetry there is another similar stress distribution in θ= 90^0 to 270^0 with σ_{max} at θ= 180^0 acting on the other piece of the coupon. Equilibrium condition requires that

$$P = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sigma(\theta).\frac{d}{2} t.\cos\theta\,.d\theta = \frac{\pi}{4} td\,\sigma_{max} = 0.785 td\sigma_{max} \quad (2)$$

Where, P is the applied tensile load at far field, t is the thickness of the base metal sheet or one half thickness of the weld nugget, d is the diameter of the weld nugget. Equation (2) relates the local maximum stress to the far field load.

B. Fatigue Life Prediction

Various fatigue life prediction criteria are classified as strain based, stress based and multiaxial approaches.

1) Stress-Based Approaches: These are based on the assumption that the range of values for stress controls the fatigue behavior of a component. They involve empirical relations between uni-axial fully reversed stress and fatigue life [10].

Modified Goodman, England, 1899

$$\frac{S_a}{S_f} + \frac{S_m}{S_{ut}} = 1 \quad (3)$$

Gerber, Germany, 1874

$$\frac{S_a}{S_f} + \left(\frac{S_m}{S_{ut}}\right)^2 = 1 \quad (4)$$

Soderberg, USA, 1930

$$\frac{S_a}{S_f} + \frac{S_m}{S_y} = 1 \quad (5)$$

Morrow, USA, 1960s

$$\frac{S_a}{S_f} + \frac{S_m}{\sigma_f} = 1 \quad (6)$$

Where,

S_a is the alternating stress, S_m is the mean stress, S_f is the fully reversed fatigue strength of the material, S_{ut} is the ultimate tensile strength, S_y is the yield strength, and σ_f is the true fracture strength.

2) Strain Based Approaches:

According to strain based approach the range of values for strain controls the fatigue life. They also take into account the effect of plastic strain and used where plastic effects dominate the fatigue behavior. Fatigue cracks usually nucleate due to plastic straining at the notches. The total strain amplitude can be resolved into elastic and plastic strain components, each of which has been shown to be correlated with fatigue life via power-law relationships for most metals. The local notch strain approach or Coffin Manson relationship relates alternating true elastic and plastic strains [1], $\Delta\varepsilon_e$ and $\Delta\varepsilon_p$, to fatigue life (N_f),

$$\frac{\Delta\varepsilon}{2} = \frac{\Delta\varepsilon_e}{2} + \frac{\Delta\varepsilon_p}{2} = \frac{\acute{\sigma}_f}{E}\left(2N_f\right)^b + \acute{\varepsilon}_f\left(2N_f\right)^c \quad (7)$$

Where, $\acute{\sigma}_f$ is the fatigue strength coefficient, $\acute{\varepsilon}_f$ is the fatigue ductility coefficient, and b and c are exponents determined by experiments.

3) Multiaxial Fatigue Criteria:

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 [18].

- 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,

$$\frac{\Delta\gamma_{max}}{2} + S_k\Delta\varepsilon_n = \frac{\acute{\sigma}_f}{E}\left(2N_f\right)^b + \acute{\varepsilon}_f\left(2N_f\right)^c \qquad (8)$$

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. (9) and (10) for the critical nodes near the nugget root. In Eqs. (9) and (10), $\varepsilon_1$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. (8) was used to predict the fatigue life ofthe specimens.

$$\frac{\Delta\gamma}{2} = \left(\frac{\varepsilon_1-\varepsilon_3}{2}\right)_{\theta_1} - \left(\frac{\varepsilon_1-\varepsilon_3}{2}\right)_{\theta_2} \qquad (9)$$

$$\frac{\Delta\varepsilon_n}{2} = \left(\frac{\varepsilon_1+\varepsilon_3}{2}\right)_{\theta_1} - \left(\frac{\varepsilon_1+\varepsilon_3}{2}\right)_{\theta_2} \qquad (10)$$

- Crossland

The Crossland criterion is a stress based multiaxial fatigue criterion which uses the second invariant of deviatoric stress tensor and maximum hydrostatic stress in its equation.

$$\sqrt{J_{2,a}} + k\sigma_{H,max} = \acute{\sigma}_f\left(2N_f\right)^b \qquad (11)$$

$$\sqrt{J_{2,a}} = \frac{1}{2\sqrt{6}}\left[(\Delta\sigma_1-\Delta\sigma_2)^2 + (\Delta\sigma_2-\Delta\sigma_3)^2 + (\Delta\sigma_1-\Delta\sigma_3)^2\right]^{1/2} \qquad (12)$$

In the above equations, $J_{2,a}$ and $\sigma_{H,max}$ are the amplitude of second invariant of deviatoric stress tensor and the maximum value of the hydrostatic stress respectively, k is a material dependent constant.

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 various section of the tailgate system shown in fig.3 by considering symmetry about Z- axis considers only one side sections.

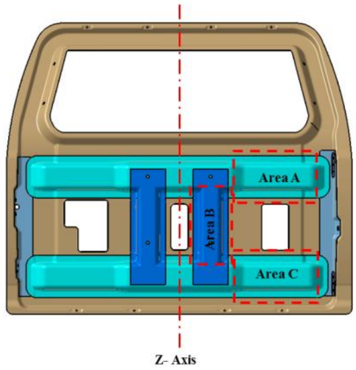

Fig.3 Tailgate areas for spot weld checking

Three areas are considered for checking static and fatigue strength of the spot weld. In selected area need to check the availability of the spot weld placing area so taking the sections at each area are,

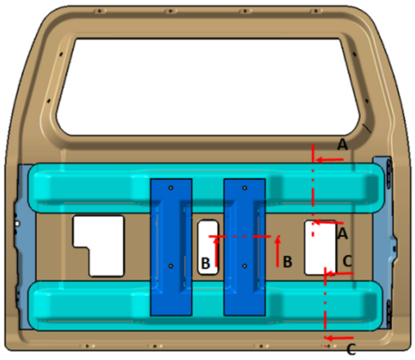

Fig.4 Tailgate sections for spot weld placing position

The sections at the selected area are shown below.

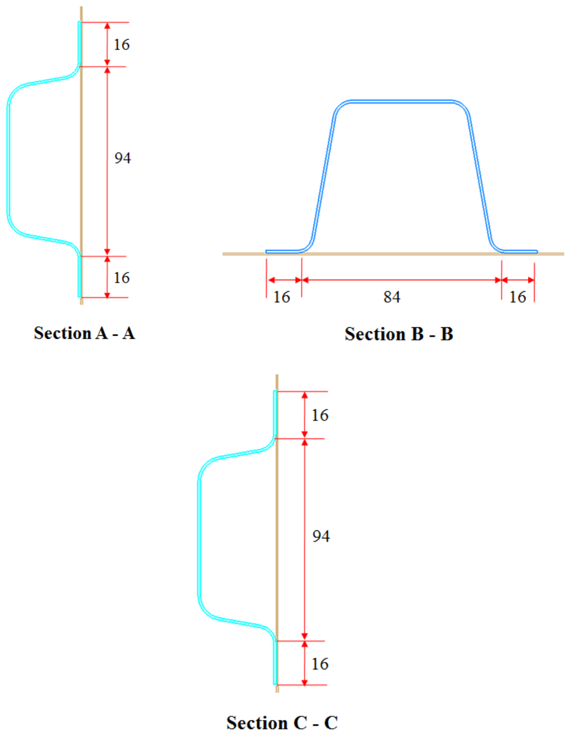

Fig.5 Tailgate sections

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 three type of spot weld position are possible, shown in fig.6, fig.7 and fig.8.

Section B–B is taken at area B. In section B-B two side16 mm resting flange vertically available for spot weld placing position. By considering section symmetry only one spot weld placing arrangement possible, shown in fig.9.

Section C-C is the same case of section A-A so need not to calculate separately.

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

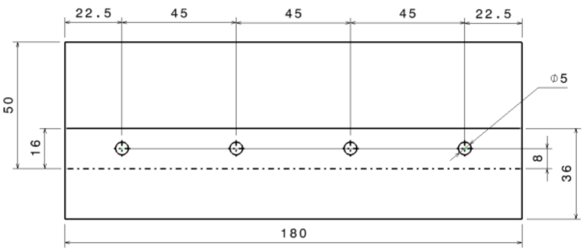

Fig.6 Type A spot weld position at section A-A

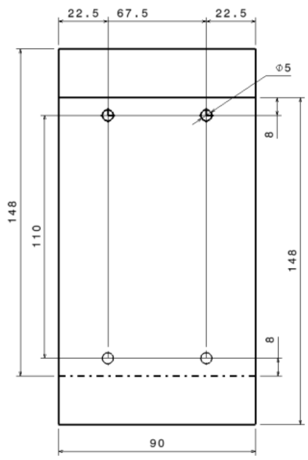

Fig.7 Type B spot weld position at section A-A

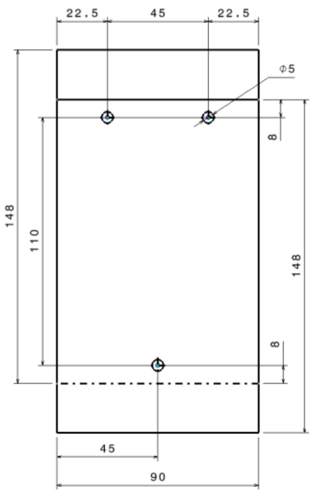

Fig.8 Type C spot weld position at section A-A

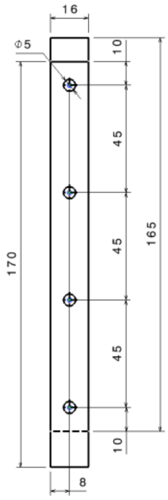

Fig.9 Type D spot weld position at section B-B

V. Finite Element Analysis

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. The boundary condition for all type of pattern are upper sheet is fix and load acting on lower sheet. In present study steel alloy ST37 are used the material properties of that material are mention in table 1.

In this study four possible spot weld arrangement are tested for static and fatigue life. Static strength of the spot weld arrangement is tested by applying longitudinal load on lower sheet. Fatigue lives of specimens were estimated by stress fatigue, strain fatigue and multiaxial fatigue criteria.

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.

The type A model, meshing, boundary condition and results are shown in below figures. The fine mesh is provided at spot weld area.

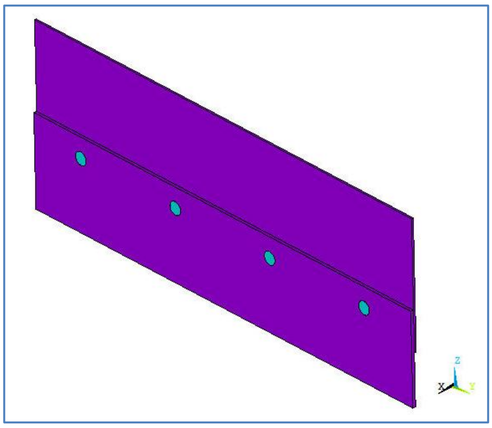

Fig.10 Type A spot weld position sample

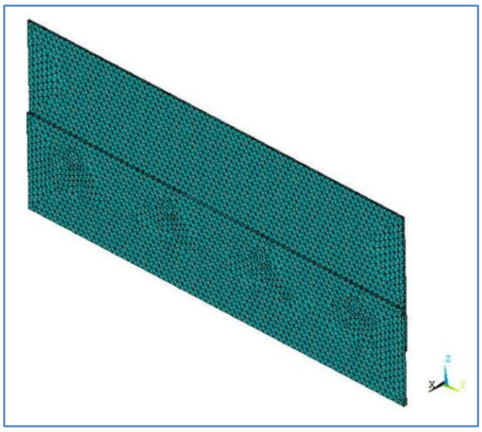

Fig.11 Type A spot weld position sample meshing

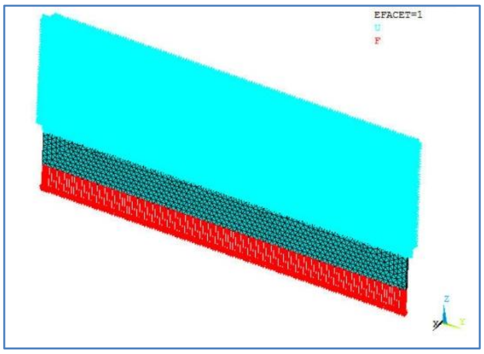

Fig.12 Type A spot weld position sample with boundary condition

TABLE I
TENSILE PROPERTIES AND STRAIN LIFE PARAMETERS OF BASE 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	795	-0.11	0.45	-0.59	0.779	458	-0.11	-0.59

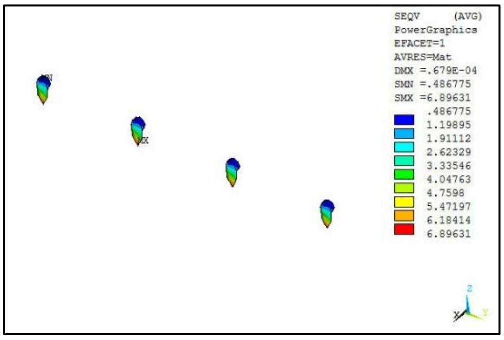

Fig.13 Type A spot weld position sample stresses in welds

VI. EXPERIMENTAL APPROACH

Simple two sheet metal panel with single spot weld sample are consider for testing. Testing is done on universal tensile testing machine (UTM) by using special fixture. The sample details are shown in below fig. 14.

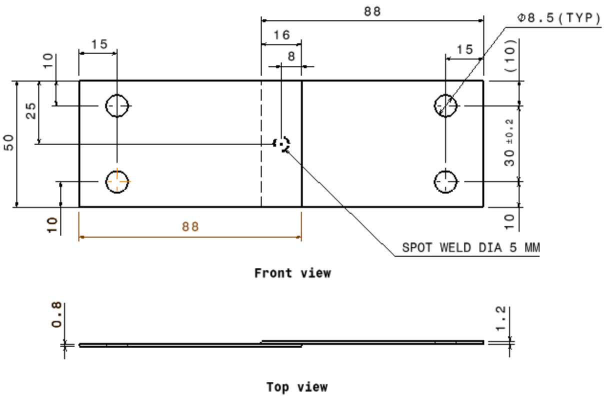

Fig.14 Spot weld testing sample details

Testing is conducted at Flora institute of technology Pune. The computer connected hydraulic UTM is shown in below fig.15.

Fig.15 Universal tensile testing machine used for testing

Simple spot weld sample shear test conducted on universal tensile testing machine by using special fixture. The special fixture with sample used for testing is shown below fig.16.

Fig.16 Special fixture used for testing

The number of samples is tested on UTM. The fracture starts at the outer area of the spot weld. After complete failure of the spot weld the spot weld material is with base metal sheet and other sheet having cracking of material. The maximum failure like the pullout failure in samples is shown in below figures.

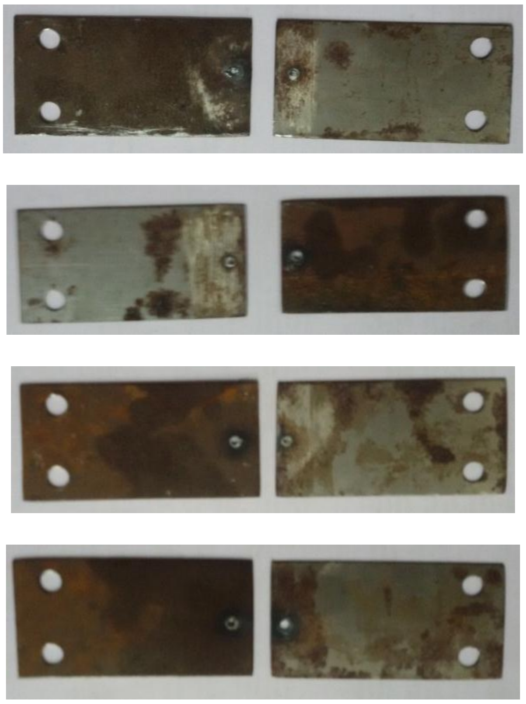

Fig.17 Tested samples

VII. CONCLUSION.

In this paper, the arrangement effects in the multi spot welded joints on the fatigue behavior of the RSW joints have been investigated by stress fatigue criteria, strain fatigue criteria and multiaxial fatigue criteria discussed. Tailgate structure is consider as symmetry about Z- axis and checking only one side of the tailgate because spare wheel is mounted at centre of the tailgate. In tailgate system three areas are consider and possible spot weld position patterns for this areas are consider for calculating the static and fatigue strength of the spot weld. Based on the obtained results, the following conclusions can be drawn from the experimental and CAE analyses:

- Type D spot weld position sample is more critical for fatigue strength point of view.
- Type A sample is more safe as compare to all samples.
- In experimental testing the failure in the spot weld occur at outer surface of the spot weld and along the thickness of the sheets.
- It was revealed that the spot welded arrangement effect has a considerable role in fatigue strength of multi-spot welded.

a)

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