Fatigue Analysis of Resistance Spot Welded Single Lap Joint using FEM

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Abstract - **The aim of this study is to prediction fatigue life of structure, the stress states developed in the structure should be determined accurately. For this purpose, a commercial FEA software, ANSYS (version 15) is used. fatigue failure thus becomes the most critical failure mode for a structure itself or the region around it under fluctuating stresses. A designer should seek the ways of increasing fatigue strength of a joint to ensure the safety of the whole structure. Resistance spot welding is the most preferred method to join metal sheets. The design variables for spot-weld joints affecting their strengths are basically sheet thickness, spot weld nugget diameter, number of spot welds and the joint type as exemplified in tensile shear (TS) specimens. In order to accurately determine the stress , a nonlinear finite element analysis was carried out taking into account plastic deformations, residual stresses developed after unloading and contacting of spot welded surfaces.**

Index Terms - **fatigue life prediction; finite element analysis; Sheet thickness; spot weld.**
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I. INTRODUCTION

The project is expected to design and fatigue analysis of the resistance spot welded with lap joint using FEM. Fatigue strength of spot-welded joints affects the structural rigidity and durability of spot-welded structures and thus it is an important factor in determining safety and structural integrity. To determine design criteria for long fatigue life for spot welded structures, accurate stress analysis and systematic fatigue strength assessment are needed. Since it is very difficult to determine directly the fatigue design criteria for actual structures, it is a typical practice to assess fatigue strengths using mock-up specimens with structural and mechanical characteristics similar to the actual structures. Many investigators have numerically and experimentally assessed fatigue strength and provided considerable data on the fatigue strength of various spot welded joints. To apply the data into the fatigue design of actual spot welded thin sheet structures, welding residual stress should be properly considered since it affects fatigue crack initiation and propagation at the nugget edge of a spot weld. Nevertheless, there are very few fatigue strength assessments that consider welding residual stress because welding residual stress analysis is quite complicated.

A key feature of the modern durability design process is the use of computer-based finite element methods to predict durability at an early stage in the design cycle. This process is driven by the need for designs with low weight, low cost of manufacture, short development cycles and good durability. Calculations based on fatigue life and realistic loading histories permit structures and components to be optimised for durability without the need for the expensive and time-consuming testing of a series of prototypes. Design analysis based on fatigue life calculations results in designs that are less conservative (i.e. better optimised) than those based on traditional criteria such as maximum load or stress for a series of standard load cases.

For fatigue analyses, the stress categories are generally evaluated by using a nominal stress, a structural hot spot stress, and a notch stress with consideration of stress concentration effects. The choice of stress category depends on the method used to express the fatigue strength data in the fatigue assessment. Among these categories, nominal stress and notch stress can be considered as the mechanical parameters for fatigue strength assessment of a spot-welded joint.

Importance of fatigue analysis on the spot welded part has grown since steel sheet having higher strength become thinner to meet the necessity of reducing the weight of an automobile effectively. Strength of spot welded part is much lower than that of its constituents and fatigue crack usually initiates from the welded point. Fatigue crack failures yields noise and vibration and often lead to fracture of structural member. The reliable methods of fatigue life prediction of spot welded joints are needed. The fatigue failure mechanism of spot welded single-lap Joint can be divided into different stages include crack growth, macro-crack growth and final fracture. Typically, the initiation site of the crack that leads to final failure of the joint is near the edge of the nugget between the two welded sheets. Hence it not easy to observe and measure the structure obstructs unaided visibility of the fatigue process.

Spot welding is a widely employed technique to join sheet metals for body and cap structure in the automotive industry. The strength of the spot welds in the unibody vehicle structure determines the integrity of the structural performance during the vehicle operations. Most spot welds generally carry only shear forces but spot welds can also experience a significant amount of peel force or the force normal to the spot weld in certain loading conditions. The combination of the stress states and geometric shapes of the spot welds lead to stress concentration that can result in fatigue crack initiation around the spot weld. Therefore, understanding of the fatigue strength for the spot welds is very important in automotive component design.

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II. EXPERIMENT

Material

. In this study, fatigue failure tests were carried out on SSTS specimens made of stainless steel (AISI304CS). The average mechanical properties and the chemical composition of stainless steel (AISI304CS)are given in Tables 1 and 2, respectively. Materials of this type are widely used in automotive industry, especially to construct body frames Although they have lower fatigue strength, they are less sensitive to notches and surface imperfections. Also, they weld evenly and easily and hold paint well. A spot-welded joint is composed of a nugget and base metal. Because elastic modulus and Poisson's ratio are not affected by heat treatment, their magnitudes remain the same throughout the specimen despite melting during the formation of the nugget. Although the non linear stress-strain relation of the material in and around the nugget was affected during the joining operation, this effect was neglected considering that the steel was not a hardened steel the hardness levels at these locations are close to each other, one may assume that there is no significant change in mechanic properties of the material during welding.

Table 1 Chemical compositions (wt %)

Material	C	CR	Ni
AISI304CS	0.02	18	10

Table 2 Mechanical properties of specimen

Material	Density (Kg/m^3)	Yield strength (Mpa)	Ultimate strength (Mpa)	Young's modulus (Mpa)	Poissons Ratio
AISI304CS	8000	215	505	2E+5	0.29

Specimen preparation

Three Single spot tensile-shear specimen(SSTS) of 1.4, 2, and 3 mm thickness and AISI304CS steel sheet is used for these specimen. Geometries of tensile- shear specimen are shown in Fig 1. Nugget diameter is 6 mm for all three specimen. Combination of material and thickness are used in different automobile parts The specimen materials of spot welded lap joint in this paper consist of stainless steel (AISI304CS) sheet for tensile-shear specimen. These materials are typically used for the automobile and train body structure.

The specimens tested in this study are made of two strips of steel sheets joined by spot welds, as shown in Fig. 1. In our case, two plates of same thickness was joined through single resistance spot welds. The shaded regions indicate the gripped portions of the specimen during testing. There are various industry standards for sizing a spot weld for a given sheet metal thickness. In this study, the specimens were made of a metal sheet having 1.4, 2 and 3 mm thickness. In the spot-weld nugget diameter was selected as 6 mm. Welding parameters are given in Table 3. In order to realize the desired nugget diameter, the joining operation was repeated using a number of different values for the welding parameters, and the set of values leading to the desired diameters was chosen. Several peel tests were also performed during the fabrication of the specimens in order to ensure that the weld nugget size did not change due to tip wear. All pieces of SSTS specimens were sheared from steel sheets. The blanks were cut in a way that the loading direction of the final specimen was parallel to the steel rolling direction. After the three pieces of the specimen were machined, they were prepared for the welding process. Each one of the three pieces was rinsed in methyl alcohol and then dried in order to remove the oil coating to avoid its adverse effect on welding. In automated _or standard_ type of spot welding process, two electrodes clamp the two sheets of metal together with a considerable force while transmitting current. A manual type of spot welding process, on the other hand, is achieved just by touching the electrode on one surface of the specimen without applying a clamping force. An electrode force of a few kgf is sufficient to achieve contact between the metal sheets.
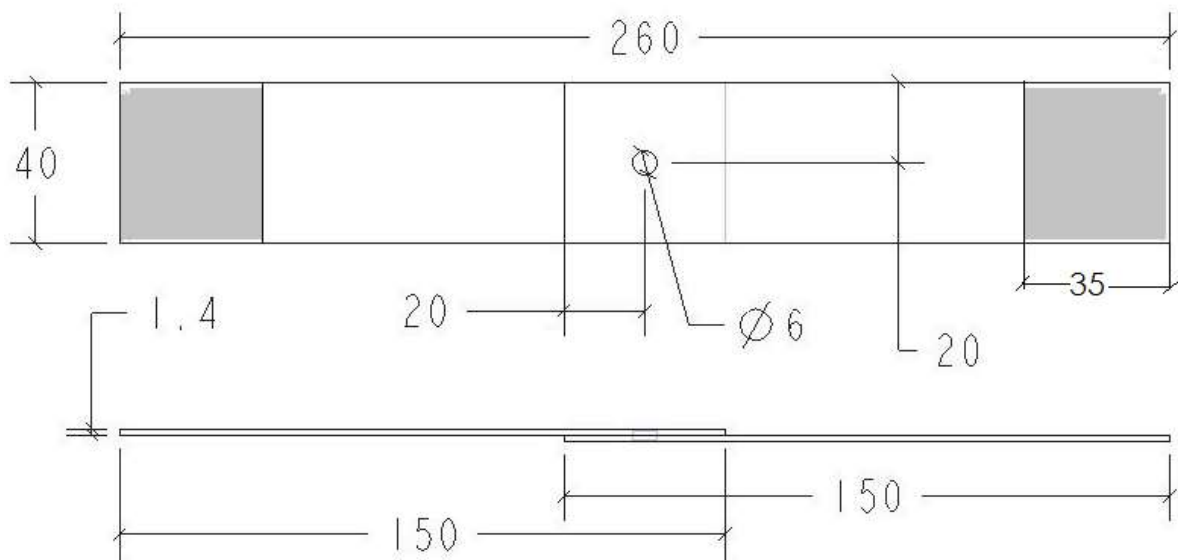
Fig. 1 Configuration of Single spot tensile-shear specimen(SSTS) (unit : mm)

Following table shows the results of test perform on different spot welded specimen details of specimen also shows in the table

Table 3 Breaking Load of different spot welded specimen

Sr. No.	Types of specimen	Thickness	Breaking Load
		mm	KN
1	Single spot welded	1.40	12.3
2	Double spot welded	1.40	11.6
3	Triple spot welded	1.40	18.3
4	Four spot welded	1.40	20.4
5	Double spot welded	2.00	11.8

Fig. 2 spot welded specimen before testing

Fig. 3 spot welded specimen after testing

III. FINITE ELEMENT ANALYSIS

In order to employ fatigue life prediction models, the stress states developed in the structure should be determined accurately. For this purpose, a commercial FEA software, ANSYS (version 15), was used. Residual stresses developed during the formation of the spot weld were not considered in the stress analysis. However, the residual stresses arising from non-uniform plastic deformations during loading were determined throughout the nonlinear stress analysis

Many different types of mechanical systems are usually uses different methods for calculations of stresses. Finite element analysis using analytical method for such system is quite difficult, but it can be make convenient by changing general machine system such as an airplane engine, transmission system, a diesel engine drive or a boat etc, to an equivalent disc and shaft system. So for same purpose simplified method has been integrated and developed which are given in this project and that can be surely used to solve for stresses of system.

For finding the shearing stresses in spot welded plate, we can use the ANSYS software. First upon we create the model in PRO-E software. ANSYS and PRO-E both are design software. In this we can find out lot of various result related with design phenomenon

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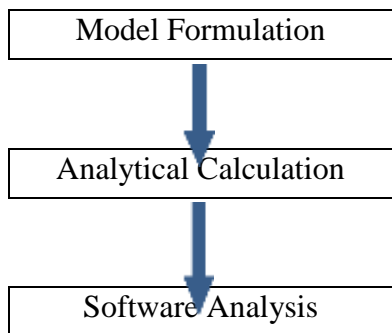
boundary conditions

The boundary conditions in the FE model of TS specimen are shown in Fig. 4. Displacements and rotations in all degrees of freedom are fixed at center. The other end is subject to uniformly distributed in-plane load cycle in the *x*-direction, while the movement is prevented in the other degrees of freedom.
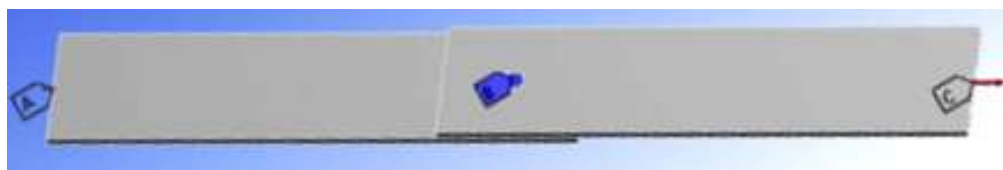

Fig. 4 The boundary conditions in the FE model

Meshing

ANSYS meshing technologies provide physics preferences that help to automate the meshing process. For an initial design, a mesh can often be generated in batch with an initial solution run to locate regions of interest. Further refinement can then be made to the mesh to improve the accuracy of the solution. There are physics preferences for structural, fluid, explicit and electromagnetic simulations. By setting physics preferences, the software adapts to more logical defaults in the meshing process for better solution accuracy.

After Meshing in ANSYS Software, find out Nodes and Element , Nodes : 37586, Element : 22356
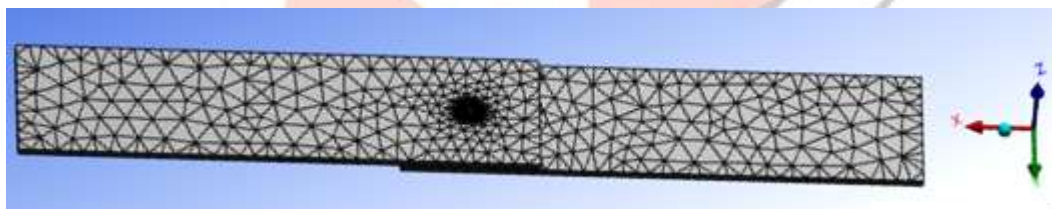

Fig.5 Meshing in the FE model

resulting stress states

Figures 6–9 show the distributions of the Single spot tensile-shear specimen(SSTS) of stress on surface at both side of nugget of the pieces of SSTS specimen, with specimens developing afterthe maximum (3000 N) and minimum loads are applied. High stresses develop on the inner surfaces of the sheets close to the peripheries of the spot-weld nuggets. The peak tensile stress develops close to the spot weld but not on its circumference. The location of the high stress conforms to the fatigue crack initiation sites experimentally observed in previous studies.

Because the minimum load is tensile and quite low, significant compressive stresses existing after unloading may only be attributed to residual stresses developed due to non-uniform plastic deformation. Although load transfer occurs through the spot-weld joint, the nugget is subject to low stresses because its thickness is large in comparison to the sheet thickness. Besides which, the nugget is mainly subject to shear loading and the plate is mainly subject to bending moment. Conse- quently, bending induces larger stresses. Due to the effect of bending, stresses change from tension to compression through the thickness as seen in Figs 6 and 7. For this reason, flexural rigidity of the plate, i.e. its resistance to bending significantly affects the stress level even though the plates are subject to in-plane loading. The pieces of SSTS specimens increase its flexural rigidity, especially at the sides. Considering that the load is transferred through the middle region, one may see why stresses are more concentrated in the SSTS specimen (Fig. 9) in comparison
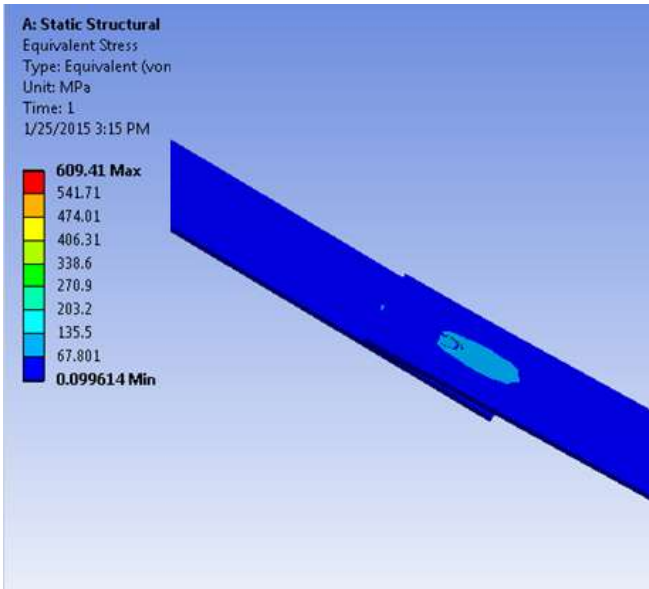
Fig. 6 Distribution of von mises stress (Max. 609.41 MPa) on surface at both side of nugget of the SSTS specimen developed due to the minimum load to 3000N (*t* = 1.4 mm, *d* = 6 mm)
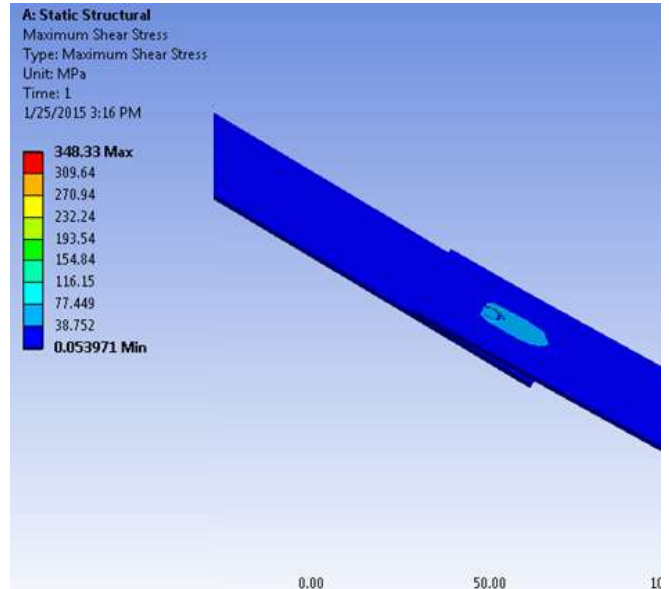

Fig. 7 Distribution of Maximum shear stress (Max. 348.33 MPa) on surface at both side of nugget of the SSTS specimen developed due to the minimum load to 3000N (*t* = 1.4 mm, *d* = 6 mm)
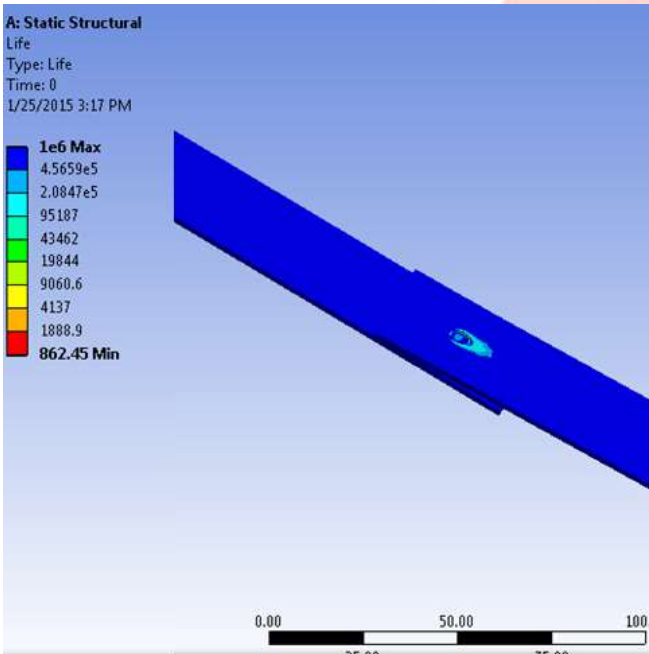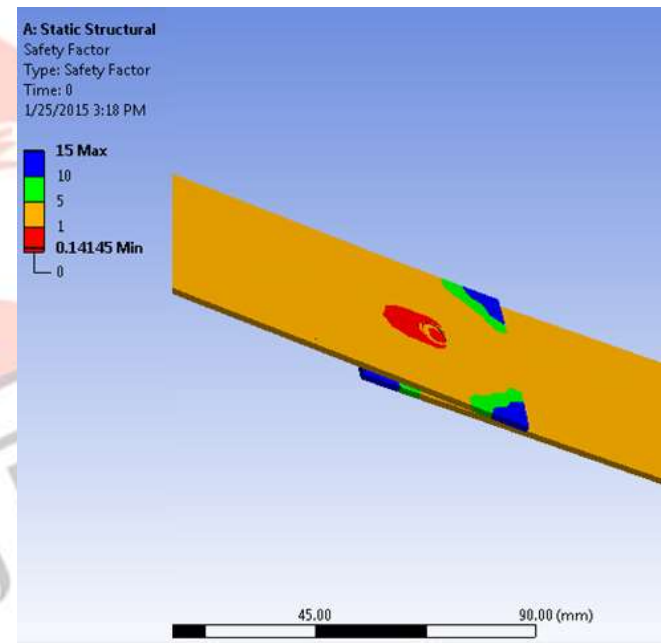

Fig. 8 Distribution of Fatigue life (Min. 862.45) on surface at both side of nugget of the SSTS specimen developed due to the minimum load to 3000N (*t* = 1.4 mm, *d* = 6 mm)

Fig. 9 Distribution of Safety Factor (Min. 0.14145) on surface at both side of nugget of the SSTS specimen developed due to the minimum load to 3000N (*t* = 1.4 mm, *d* = 6 mm)
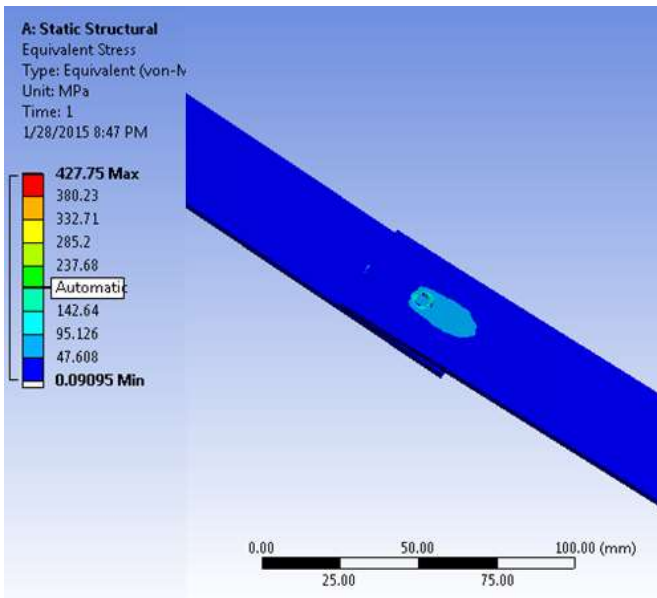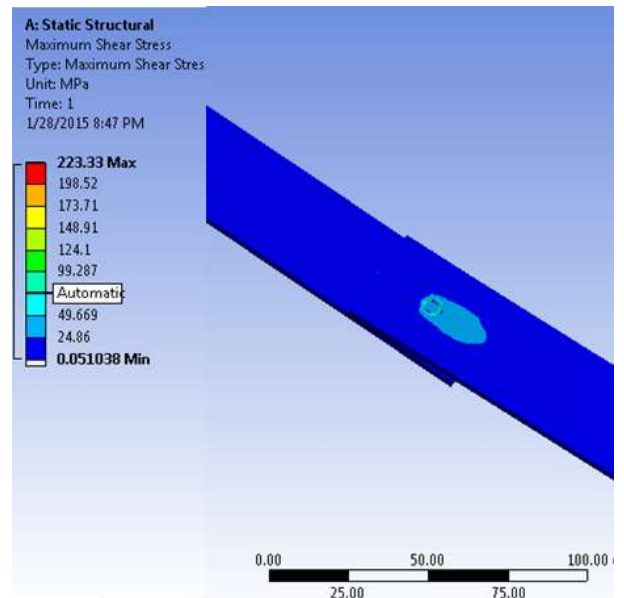
Fig. 10 Distribution of von mises stress (Max. 427.75 MPa) on surface at both side of nugget of the SSTS specimen developed due to the minimum load to 3000N (*t* = 2 mm, *d* = 6 mm)

Fig. 11 Distribution of Maximum shear stress (Max. 223.33MPa) on surface at both side of nugget of the SSTS specimen developed due to the minimum load to 3000N (*t* = 2 mm, *d* = 6 mm)
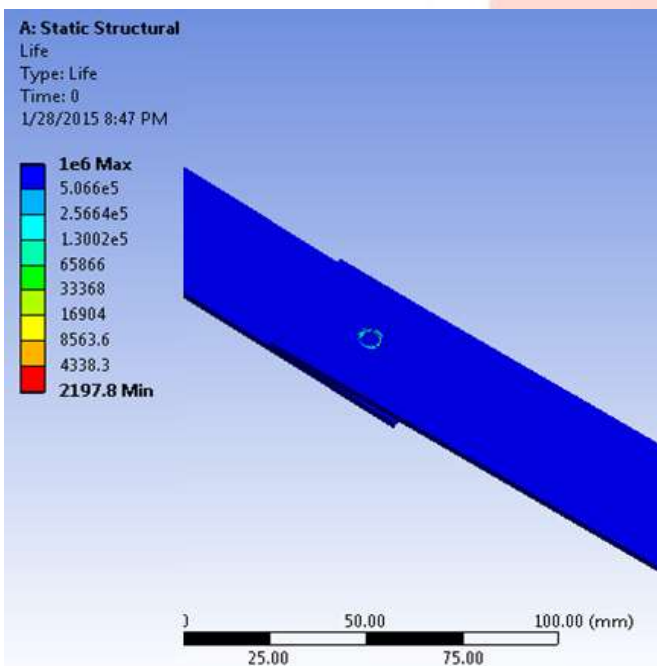

Fig. 12 Distribution of Fatigue life (Min. 2197.8) on surface at both side of nugget of the SSTS specimen developed due to the minimum load to 3000N (*t* = 2 mm, *d* = 6 mm)
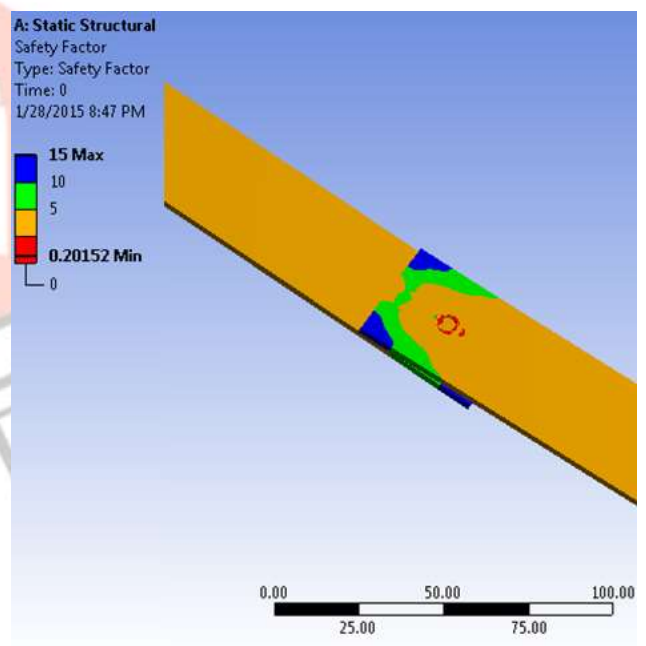

Fig. 13 Distribution of Safety Factor (Min. 0.20152) on surface at both side of nugget of the SSTS specimen developed due to the minimum load to 3000N (*t* = 2 mm, *d* = 6 mm)

Figures 10–13 show the distributions of the Single spot tensile-shear specimen(SSTS) of stress on surface at both side of nugget of the pieces of SSTS specimen, with specimens developing afterthe maximum (3000 N) and minimum loads are applied. High stresses develop on the inner surfaces of the sheets close to the peripheries of the spot-weld nuggets. The peak tensile stress develops close to the spot weld but not on its circumference. The location of the high stress conforms to the fatigue crack initiation sites experimentally observed in previous studies

Figures 12 show the distributions of Fatigue life with application of minimum load (N) to 3000N load minimum Life fund to be 2197.8 and thickness and diameter are 2 and 6 mm respectively, Figure 13 show the distributions of Safety Factor with application of minimum load (N) to 3000N load minimum Safety factor fund to be 0.20152

Results of Software analysis

fatigue life prediction models, the stress states developed in the structure should be determined accurately. For this purpose, a commercial FEA software, ANSYS (version 15), was used. Residual stresses developed during the formation of the spot weld were not considered in the stress analysis.

Followings are the results of single lap spot welded joint on different load range by using different thickness specimen-, von-Mises Stress, Maximum Shear Stress ,Fatigue life, safety factor

Thickness (mm)	Fatigue Load (N)	Von-Mises Stress (MPa)	Max. Shear Stress (MPa)	Fatigue life (times)	Safety factor
1.4	1500	304.7	174.17	6270.6	0.2829
	2000	406.27	232.22	2577.1	0.21217
	2500	507.84	290.28	1385.6	0.16974
	3000	609.28	348.33	862.45	0.14145
2	1500	213.87	111.67	20043	0.40304
	2000	285.16	148.89	7696.1	0.30228
	2500	356.46	186.11	3861.3	0.24182
	3000	427.75	223.33	2197.8	0.20152
3	1500	193.93	110.66	28702	0.44449
	2000	258.58	147.54	10461	0.33336
	2500	323.22	184.43	5225.4	0.26669
	3000	387.86	221.31	2974.2	0.22224

Table 4 - Results of Software analysis

Estimated fatigue lives

In a mechanical component under fluctuating loads, the process of nucleation, growth and joining of micro-cracks is expected to take place in highly stressed regions. Fatigue crack growth is known to occur along planes where the tensile stress takes its maximum value. Accordingly, the fatigue life calculations were carried out using the stress states in the element at which the maximum tensile stress develops. This element is located on the surface around the peripheries of the spot welds as shown in Figs 09 and13.

Comparison of the predicted and measured fatigue lives

The accuracy of the fatigue life predictions was verified by comparing them with the fatigue lives of SSTS specimens of different thickness experimentally obtained by analytical calculation. The FE calculations were carried out using the material properties, loading and geometry of the specimens provided in those studies.
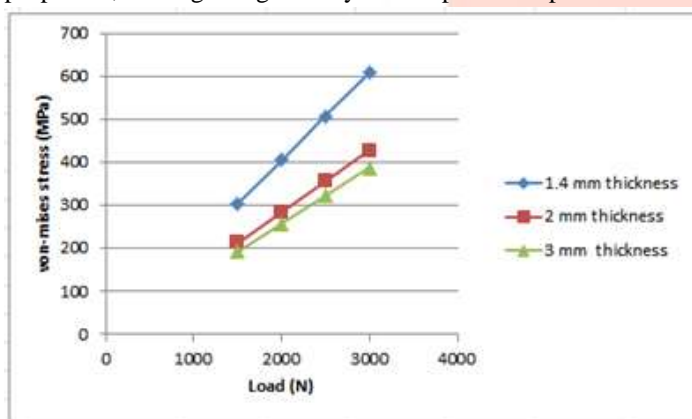

Fig. 14 Comparison of predicted fatigue lives with Load range (N)and von mises stress (MPa) for different thickness (t1=1.4mm, t2=2mm,t3=3mm)
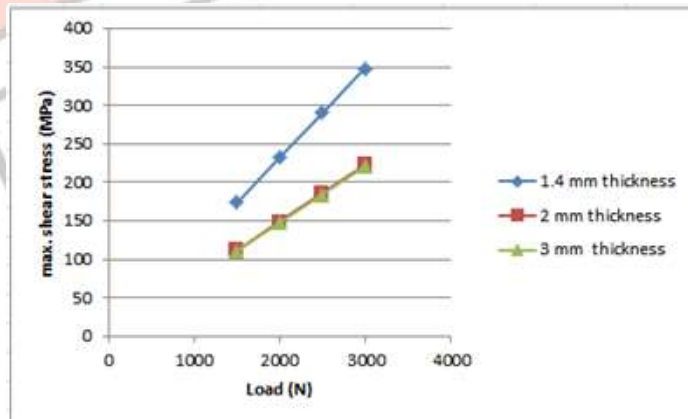
Fig. 15 Comparison of predicted fatigue lives with Load range (N)and Maximum shear stress (MPa) for different thickness (t1=1.4mm, t2=2mm,t3=3mm)

Fig. 14 shows the variation in von-mises stress (MPa) with load (N). It was found that there is a direct relationship between the von-mises stress (MPa) with load (N). As the load increases the von-mises stress is also increases. In this experiment we found that below 2 mm plate thickness the von-mises stress drastically increased and for the thickness 2mm and 3mm the values are much closed. As plate thickness increases the von-mises stress (MPa) decreases.

Fig. 15 shows the variation in maximum shear stress (MPa) with load (N). It was found that there is a direct relationship between the maximum shear stress (MPa) with load (N). As the load increases the shear stress is also increases. In this experiment we found that below 2 mm plate thickness the shear stress drastically increased and for the thickness 2mm and 3mm the values are very closed. For 2mm thickness and 2000N load the maximum shear stress value is 150 Mpa and for 1.40 mm thickness and 2000N load the maximum shear stress value is 240 Mpa.
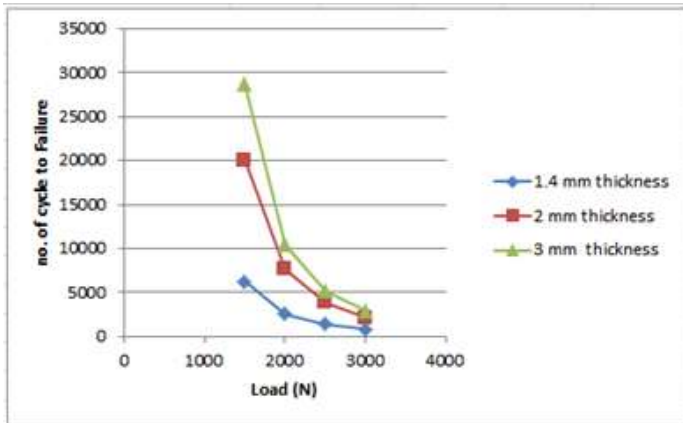
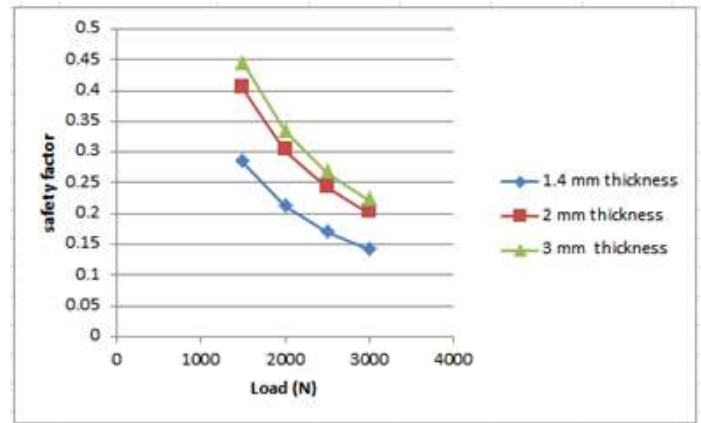**Fig. 16 Comparison of predicted fatigue lives with Load range (N)and number of cycle to Failure for different thickness (t₁=1.4mm, t₂=2mm,t₃=3mm)**

Fig. 17 Comparison of predicted fatigue lives with Load range (N)and safety factor for different thickness (t₁=1.4mm, t₂=2mm,t₃=3mm)

Fig. 16 shows the no. of cycle to failure with load (N). It was found that there is an inverse relationship between the safety factor and load (N). As the load increases the no. of cycle to failure is decreases. In this experiment we found that at the value of load 3000N the values of no. of cycle to failure is very closed

Fig. 17 shows the variation in safety factor with load (N). It was found that there is an inverse relationship between the safety factor and load (N). As the load increases the safety factor is decreases. In this experiment we found that below 2 mm plate thickness the safety factor drastically increased and for the thickness 2mm and 3mm the values are much closed. As plate thickness increases the safety factor decreases

Results of Analytical calculation

Followings are the results of single lap spot welded joint on different load range by using different thichness specimen- von-Mises Stress,

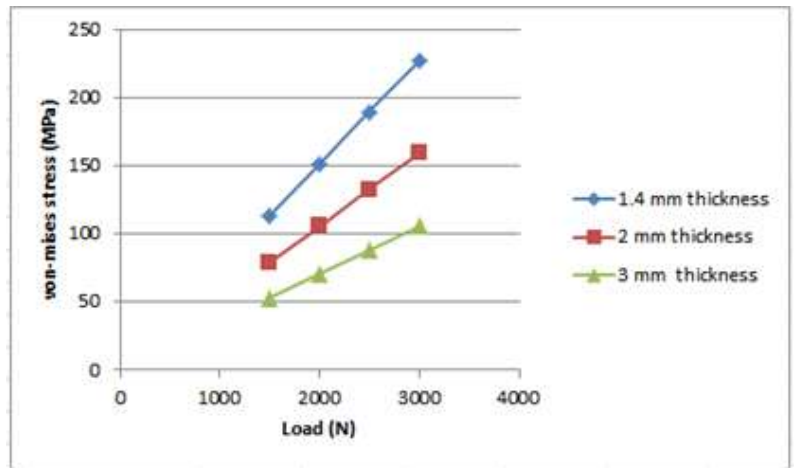| thickness (mm)	fatigue load (N)	von-mises stress (MPa)
1.4	1500	113.68
	2000	151.57
	2500	189.47
	3000	227.36
2	1500	79.53
	2000	106.1
	2500	132.62
	3000	159.15
3	1500	53.05
	2000	70.73
	2500	88.41
	3000	106.1

Table 5- Results of Analytical calculation

Fig. 18 Comparison of predicted fatigue lives with Load range (N)and von mises stress (MPa) for different thickness (t₁=1.4mm, t₂=2mm,t₃=3mm)

Fig. 18 shows the variation in von-mises stress (MPa) with load (N) on the basis of analytical calculations. It was found that there is a direct relationship between the von-mises stress (MPa) with load (N). As the load increases the von-mises is also increases.similarle in software analysis also showes the graph of von mises stress with load (N) the nature of graph is nearly same. In this experiment we found that below 2 mm plate thickness the von-mises drastically increased and for the thickness 2mm and 3mm the values are much closed. As plate thickness increases the von-mises stress (MPa) decreases.

IV RESULTS AND DISCUSSIONS

Fatigue life of sheet 1.40 mm thickness and 2 mm thickness is more than the difference of fatigue life between 2 mm and 3 mm thickness plate. So from this we concluded that 2 mm thickness sheet is best suitable for spot weld structure to overcome the fatigue failure. In this project, we have to calculate the total deformation, von-Mises stress and Max Shear Stress of single lap

welded plate with the help of FEA software i.e, ANSYS software Static Structural Analysis. Similarly difference of these stresses of sheet 1.40 mm thickness and 2 mm thickness is more than the difference of these stresses between 2 mm and 3 mm thickness plate. So from this we concluded that 2 mm thickness sheet is best suitable for spot weld structure to overcome the fatigue failure. Comparing the nature of graph of von-mises stress (MPa) with load (N) on the basis of analytical calculations and software analysis is showes nearly same nature

V CONCLUSION

In this study, we conclude that the fatigue failure analysis of spot welded single lap joint with the help of ANSYS software. A software system has been developed for the fatigue life prediction of spot welds. A computational technique developed and has been applied to predict the fatigue life of spot welded structures in tensile loading. . It was observed that the von-Mises Stress is maximum for 1.4 mm thickness sheet and minimum for 2.0mm and 3.0 mm thickness sheet. So it is found that difference of these stresses of sheet 1.40 mm thickness and 2 mm thickness is more than the difference of von-mises stresses between 2 mm and 3 mm thickness plate. So from this we concluded that 2 mm thickness sheet is best suitable for spot weld structure to overcome the fatigue failure.

VI ACKNOWLEDGMENT

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