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# Analysis of the Bolted Joint used in Composite Leaf Spring for Stress Concentration

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***Abstract*- If the last decades are observed, the use of composite materials in automobile sector is steadily growing. The instant increased applications of composite material in the automobile sectors compared to the conventional materials such as steel is because of these materials offer various advantages. The aim of this project is to focus over the investigation of the stress concentration factor of the bolted joints in the composite leaf springs. The work also gives focus on the application of FEA concept to compare two types of bolted joints and propose the one having less stress concentration factor. Two bolted joints used for comparison are protruded and countersunked type. The solid modeling of bolted joint assembly is done by CATIA V5R20, meshed with Hypermesh 12.0 and analyzed using ANSYS 14.5. The process of validation is sought through the physical Experimentation. The results of Experimental work will be compared for results with the numerical methodology and vice-versa. The concurrence of the results will offer validation for this thesis work.**

**Keywords - Bolted Joint, Composite Leaf Spring, Protruded and Countersunked bolted joints, Stress Concentration.**

## I. INTRODUCTION

Increasing competition and inventions in automobile sector tends to modify the existing products or replacing old products by new and advanced material products. And also to meet the needs of the natural resources conservation, energy and economy, the automobile manufacturer have been attempting to reduce the weight of the vehicle in recent years.

A suspension system is very important area where these innovations are applied resulting in the increase in efficiency and load bearing capacities. In weight transport, it is required to design such a product which will have high load bearing capacities as well as less weight.

The all requirements mentioned above are met by introduction of composite materials as it is having less weight compared to conventional materials and high load carrying capacity. Compared to steel spring, the composite leaf spring is found to have 65% higher stiffness and 126.98% higher natural frequency than that of existing steel leaf springs.

Figure 1: Composite Leaf Spring

In automobile suspension system, manufacturing of composite components have some limitations. Such parts are designed to be able to withstand a high level of shock loads. Therefore, to provide an efficient automobile design, the composite parts are joined by mechanically fastened joints. Another advantage of use of bolted joints is that it will provide ease in disassembling. Moreover it gives access for inspection and repairing also. Bolted joints are used to attach the leaf springs to the automobile chassis for the shock transfer. The operating principle of bolted joints is based on the microscopic and macroscopic mechanical interference, such as friction between the joined parts, shear or tensile transfer forces between the joined components. By the use of this property, different materials can be fastened by means of mechanical joints. Every parts have advantages as well as disadvantages. The major joints imperfection is based on a concentration of high stresses at the bolt hole induced by "notch effect" due to hole presence. Some parts lead to corrosion. Hole generation requires specific drilling techniques taking into account the possibilities of mechanically and thermally induced defects. Different techniques such as abrasive jet drilling etc are used to enhance the efficiency of the hole in bolted joints.

Figure 2: Typical Bolted Joint

The proposed method uses software in the FEA domain for analyzing the effects of the variation in the values of the design parameters affecting the modal behavior. Also the numerical approach will give the results more close to practical values through simulation. The FEM technique is used to analyze the stress state of an elastic body with complicated geometry.

## II. LITERATURE REVIEW

Sushil B et al. focused on the reduction of weight of light vehicle in 2015. To solve problem in this regard composite materials were selected by them. The main scope of this work is to reduce the overall weight of suspension system and increase load carrying capacity of the leaf spring using composite material. Stress and deflection are the design parameters considered for the analysis. The work also gives focus on the application of FEA concept to compare two materials for leaf springs and fine the optimum one. Here they have used leaf springs made up of E- glass fibre. In this work, the solid modeling is done by Catia V5 and the analysis using Ansys 14.5. The total force acting on the leaf spring was considered as 4600 N with the help of numerical calculations. With the help of theoretical method they found the values of bending stress and deflection. They compared FEA and theoretical results. They concluded that stress produced in composite material are less as compared to conventional steel springs. However the FEA results and theoretical results varied. B Raghu Kumar et al. in 2013, suggested the best composite material for design and developement of complete mono composite leaf springs. A single leaf with variable thickness and width for constant crossectional area of different composite materials, with similar mechanical and geometrical properties to the conventional springs were modeled and analyzed. They used materials like steel, E glass epoxy, Graphite epoxy, Boron aluminium, Carbon Epoxy, Kevlar Epoxy. From the results, Graphite Epoxy, carbon and Kevlar Epoxy are getting more stress as compared to steel. Boron aluminium and Epoxy glass are getting less stresses compared to steel. Finally it is concluded that Boron aluminium is best suitable material for replacing the steel in manufacturing of mono leaf spring. Since its stresses and weight is considerably low with other. [3] S. Rajesh et al. carried out the experimental investigation on laminated composite leaf springs which were subjected to cycling loading. They took the dimensions of an existing conventional leaf springs of a light commercial vehicle to fabricate a special die for the manufacturing various composite leaf springs. Material like GFRP, CFRP, C-GFRP, G-CFRP were fabricated hand lump technique and tested by universal testing machine. Main focus was to measure load per deflection and maximum load. The cyclic loading with specific duration was given by milling machine. They applied cyclic loads such as 3780 cycles, 7560 cycles and 11340 cycles. From experimental results, the glass carbon hybrid composite leaf springs are replaced in the automobiles. An improved vehicles performance will be obtained with appropriate load bearing properties due to lower weight. [4] Starikov et al. investigated about the fatigue behaviour in composite joints through the experiment. In this experiment. Composite plates were bolted by six fasteners made of titanium. The specimens were subjected to fatigue loading with stress ratio R= -1. Strain guage measurements were done to analyse strain distribution and load transfer between the bolt rows. An extensiometer was used to observe the bolt movement. The experiment showed that the titanium fasteners have excellent fatigue resistance properties. This paper shows that the failures occurs due to the bolts. To prevent specimen bending and out of plane deflection an aluminium lateral support was mounted. Finally, it concludes the fatigue behavior of specimens bolted by fasteners have shown that these joints perform excellent fatigue resistance properties. [6] Starikov et al. carried out the experimental fatigue analysis to observe the fatigue behavior of composite joints with hexagonal protruding bolts. In this experiment, single, double and triple row double lap joints were tested in cyclic loading with stress ratio = -1. In order to study the development of fatigue damage in the joints bolt movement, relative displacement between composite plates, and strain guage measurement were used. It is concluded that the strain guage measurements between the bolts showed that the bolt presence has a significant effect on the strain evolution during fatigue tests. [7] Stocchi C et al. investigated on the mechanical behavior of the single lap composite joints with countersunk bolts. They have done it numerically as well as experimentally. FE model was developed and the distribution of the six stress components around the holes of the composite joints was studied with thw effect of position of the bolt. This paper consists of both static and fatigue analysis performed numerically and experimentally. A method to monitor bolt clamping force and detect crack initiation and propagation during the fatigue tests has been developed. The method used allows the study of loss of clamping force due to cyclic loading. Saleem et al. investigated the influence of two drilling processes on the mechanical behaviour of bolted composite joints. Two stacking sequence i.e. $(+45)_{2s}$ and (90/+45/0/-45) were studied. In this work, specimens were drilled with the use of conventional machining and abrasive jet machining. Infrared thermographs were used to determine high cycle fatigue strength and monitor damage accumulation and heat dissipation. This paper concludes that in case of high loads, the damage accumulation in bolted joints composite specimens drilled with CM was at least 20% more than that of these drilled with AWJM. CM specimens experienced fastened pull through and shear out failure mode whereas AWJM specimens only fastener pull through failure mode was present. Fatigue strength for bolted composite joints drilled with AWJM was approximately 20% higher than those drilled with CM. [9]

Conclusion from Literature Survey:

The influence of the bolt movement and friction forces on the joint behavior has appeared to be very important during loading. Therefore, to study their influence on the load transfer of applied load between bolt rows and local strain using FEM approach would be of interest.

The failure in the bolted joints mainly occurs due to the bolt failures. Local fatigue behavior in composite joints with countersunk fasteners has to be analysed since the load transfer of applied load in bolted plates with countersunk and ordinary holes is different. More fractographic observations are needed in order to study the extent of fatigue damage in bolted laminates tested at different load levels. This will highlight the mechanisms of fatigue damage in the joint system and the influence of individual bolts on them during fatigue testing.

PROBLEM STATEMENT

A bolted joint in a composite leaf spring is to be investigated. The double lap joint is formed in which the outer plates are made up of steel and the sandwiched is of composite material i.e. E-glass/ epoxy composite. Protruded hexagonal bolts are used to join the plates. The purpose is finding an optimized design of bolt connection in the composite leaf spring with the highest strength, safe failure mode and less stress concentration factor. Hence the use of countersunk bolt will be done to investigate the stress concentration over the plates and predict the fatigue life of the joint experimentally.

OBJECTIVES

- To develop the experimental setup which will support the leaf spring and proper force to be given to assembly.
- To find the stresses introduced in the different configuration and composite plate with the help of strain gauges.
- Further find the Fatigue life of the leaf spring.

METHODOLOGY

1. Study the existing System
2. Study the 3D model
3. Identify the design parameters for improvement
4. Discretization of the component
5. CAE Solver preparation
6. Studying the results
7. Identify the design parameters for improvement
8. Revise the geometry and analysis
9. Physical experimentation for benchmarking study
10. Recommendation of solution

## III. ANALYSIS OF BOLTED JOINT

### *1. Calculations for Forces on Leaf Spring*

Weight and Initial measurements of Four Wheeler:

Curb weight of vehicle: 800 kg

Maximum load carrying capacity: 600 kg

Total weight: 800+600 = 1400 kg

Factor of safety (FOS) = 2

Acceleration due to gravity = 10 $m/s^2$

Therefore total weight,

W= 1400*10*2 = 28000N

Since the vehicle is 4-wheeler, the load acting on each leaf spring is divided by 4,

F= 28000/4 = 7000N

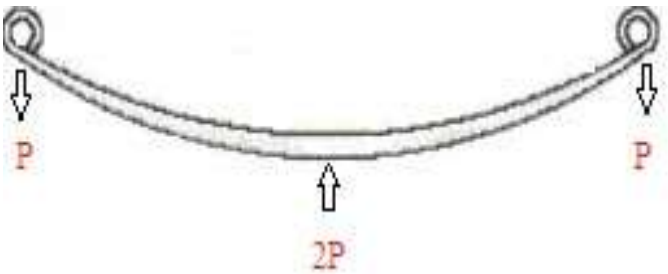



Figure 3: Forces acting on Composite leaf spring

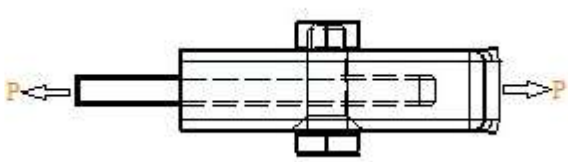



Figure 4: Bolted joint in Composite leaf spring

From above Figure, we have,

2P = F = 7000 N

P = 3500 N = 3.500 KN

### *2. Material Properties*

Steel Plates:

Plain carbon steel 20C8 in hot rolled and normalized condition

$S_{ut}$ = 440 $N/mm^2$

Poisson ratio = 0.3

Composite plate:

E-glass/ Epoxy composite of 60% fibre volume

Tensile modulus along X direction ($E_x$) = 14000 MPa

Tensile modulus along Y direction ($E_y$) = 6030 MPa

Tensile modulus along Z direction ($E_z$) = 1530 MPa

Tensile strength of the material = 800 MPa

Compressive strength of the material = 450 MPa

Shear modulus along XY direction ($G_{xy}$) = 2433 MPa

Shear modulus along YZ direction ($G_{yz}$) = 1600 MPa

Shear modulus along XZ direction ($G_{xz}$) = 2433 MPa

Poisson ratio along XY direction ($\upsilon_{xy}$) = 0.217

Poisson ratio along YZ direction ($\upsilon_{yz}$) = 0.366

Poisson ratio along XZ direction ($\upsilon_{xz}$) = 0.217

3. *Design for Bolts*:

Bolt material:

Plain carbon steel: 30C8

$S_{yt}$ = 400 N/mm$^2$, FOS = 5

P = 3.500 KN

Shear area of bolts = Number of bolts * area

$$= 2 * (\frac{\pi}{4}d^2)\ mm^2$$

Therefore,

$$P = 2 * (\frac{\pi}{4}d^2)\ \tau$$

$S_{sy} = (0.5 * S_{yt}) = 0.5 * 400 = 200$ N/mm$^2$

$\tau = (S_{sy} / FOS) = (200/5) = 40$ N/mm$^2$

Putting the values in equation, we get,

$3.500 * 10^3 = 2 * (\frac{\pi}{4}d^2) * 40$

$d^2 = 55.7042$

d = 7.46 mm or 8 mm

Standard size to be selected is M8.

Calculations for Stress Concentration Factor:

4. *For steel plates with Simple hole:*

Material: 20C8 ($S_{ut}$ = 440N/mm$^2$)

P = 3.500 KN =3500 N

w = 76mm, d = 8mm, t = 14mm

Nominal stress $\sigma_0$,

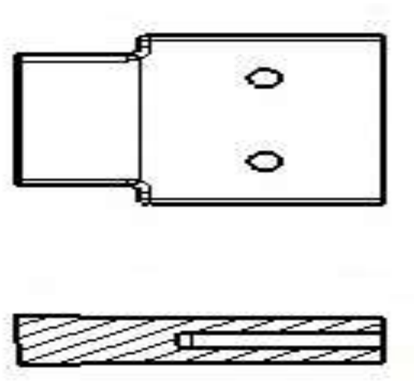


Figure 5: Steel plates in Bolted joint

$$\sigma_0 = \frac{P}{((w-2d)t)}$$

$$\sigma_0 = \frac{3500}{((76-2*8)14)}$$

$\sigma_0$ = 3500/840 = 4.1666 N/mm$^2$

(d/w) = (16/76) = 0.210526

From [1],

$K_t$ = 2.5

We have,

$K_t = (\sigma_{max}/ \sigma_0)$

$\sigma_{max}$ = 2.5 * 4.166

$\sigma_{max}$ = 10.4166 N/mm$^2$

We have $\sigma_{max} = (S_{ut}/FOS) = (440/ 4) = 110$ N/mm$^2$

So required $\sigma_{max}$ is less than obtained $\sigma_{max,}$ hence we can say that design is safe.

5. *For Composite Plates:*

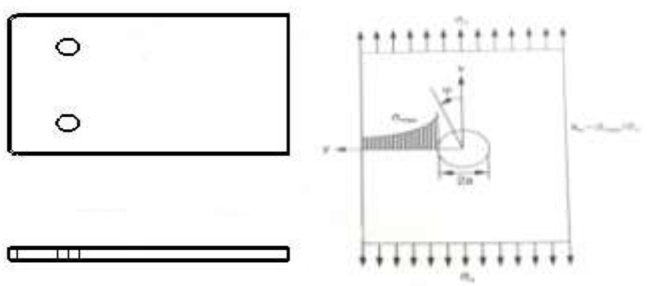


Figure 6: Composite plate in Bolted joint

For an orthotropic laminate with a hole under uniaxial loading along a principal axis x, the maximum stress is the circumferential stress on the hole boundary at $\phi = 90^0$. The stress concentration at this location is obtained as,

$k_\sigma = (\sigma_{max}/\sigma_0) = 1+\sqrt{(2\left[\sqrt{\frac{Ex}{Ey}} - \upsilon xy\right] + (\frac{Ex}{Gxy}))}$

where,

$\sigma_0$ = applied far field average stress,

$\sigma_{max}$ = maximum circumferential stress on hole boundary

(at $\phi = 90^0$)

$E_x$, $E_y$ = average Young's moduli in the x and y directions

$G_{xy}$ = average shear modulus

$\upsilon_{xy}$ = average poisson's ratio

putting the values from above properties, we get,

$k_\sigma = 3.89265$

6. *For Steel plates with Countersunk Hole:*

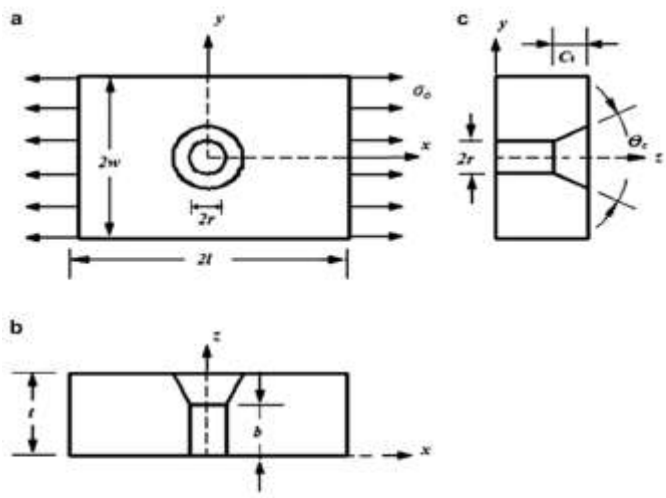



Figure 7: Configuration of Countersunk hole [8]

The general form of the stress concentration factor equation is given below,

$$K_t = K_h * K_{ss} * K_{cs} * K_{\Theta c}$$

Where, $K_h$ is the first constituting factor that carries the effect of the width of the plate on $K_t$, $K_{ss}$ is the second constituting factor that carries the effect of the plate thickness on $K_t$, $K_{cs}$ is the third constituting factor that carries the effect of the countersunk depth, and finally $K_{\Theta c}$ the fourth constituting factor that carries the effect of the countersunk angle. [8]

The dimensions are $C_s$=5mm, 2r=8mm, 2W=38mm, t=14mm, $\Theta_c$= 90.

For the above configuratiuon we have the values,

$\left(\frac{t}{r}\right) = 1.75,\ \left(\frac{C_s}{t}\right) = 0.35,\ \left(\frac{r}{W}\right) = 0.2105,\ \theta_c = 90$

The formulation of the factors mentioned above is given below,

$K_h = 3+\left(\frac{\left(\frac{r}{w}\right)^{1.4}}{1-\left(\frac{r}{w}\right)^{0.5}}\right) = 3 + \left(\frac{(0.2105)^{1.4}}{1-(0.2105)^{0.5}}\right) = 3.208426$

$K_{ss} = = 1 + \frac{0.3\left(\frac{t}{r}\right)}{5+\left(\frac{t}{r}\right)^2} = 1 + \frac{0.3\,(1.75)}{5+(1.75)^2} = 1.06511$

$K_{cs} = 1 + \left(\frac{r}{w}\right)^{1.8}\left(\frac{t}{r}\right)\left(\frac{C_s}{t}\right) + 0.28\left(\frac{t}{r}\right)^{0.1}\left(\frac{C_s}{t}\right)$

$+ 0.1\left(\frac{t}{r}\right)^{1.5}\left(\frac{C_s}{t}\right)^2$

$K_{cs} = 1 + (0.2105)^{1.8}(1.75)(0.35) + 0.28\,(1.75)^{0.1}(0.35) + 0.1\,(1.75)^{1.5}(0.35)^2$

$K_{cs}$ = 1+ 0.033706+0.10364+0.02835

$K_{cs}$ = 1.16905

$K_{\Theta c} = 1 + m\,(\Theta_c - 100^0)$

Where $m = A_1\left(\frac{t}{r}\right)^{\gamma}$

$A_1 = \frac{C_s}{t}\left(-0.003 + 0.078\left(\frac{C_s}{t}\right) - 0.078\left(\frac{C_s}{t}\right)^2\right)$

$=0.35\,(-0.003 + 0.078(0.35) - 0.078(0.35)^2)$

$= 0.35\,(-0.003+0.0273-(9.5555*10^{-3}))$

$A_1 = (5.160*10^{-3})$

$\Upsilon = \frac{C_s}{t}\left(3.6 - 9.6\left(\frac{C_s}{t}\right) + 7.8\left(\frac{C_s}{t}\right)^2\right)$

$= \frac{C_s}{t}\,(3.6 - 9.6(0.35) + 7.8(0.35)^2)$

= 0.35(3.6-3.36+0.9555)

$\Upsilon$ =0.4184

Putting in equation of m. we get m= $(6.52133*10^{-3})$

Hence $K_{\Theta c}$ = 0.9347.

We put values in stress concentration equation stated above,

$K_t = K_h * K_{ss} * K_{cs} * K_{\Theta c}$

= 3.2084 * 1.065 * 1.16905 * 0.9347

$K_t$ = 3.7337

## IV. NUMERICAL ANALYSIS

Modelling Software : Catia V5R20

Preprocessor : Hypermesh

Solver : ANSYS 14.5

Post Processor : ANSYS 14.5

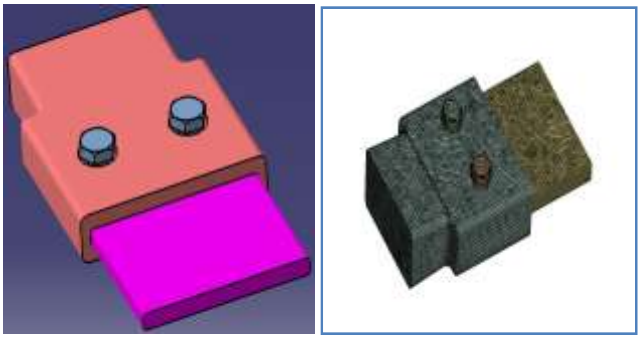


Figure 8: Meshed model of the Protruded bolted joint.

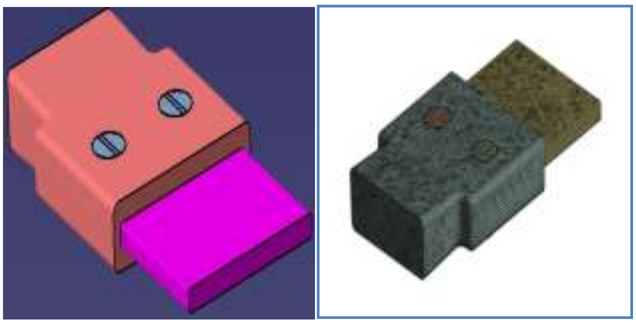


Figure 9: Meshed model of the Countersunked bolted joint.

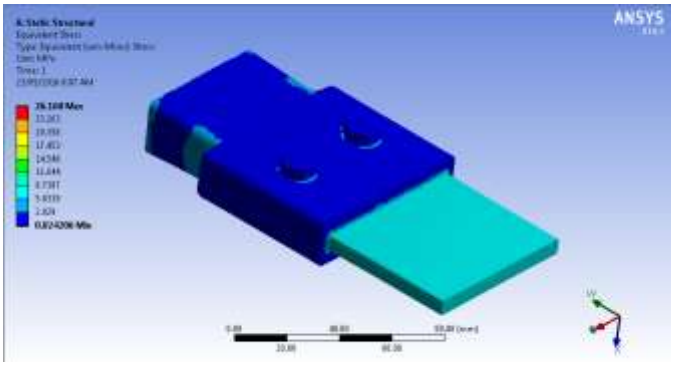


Figure 10: Equivalent Stress of Protruded Bolted Joint

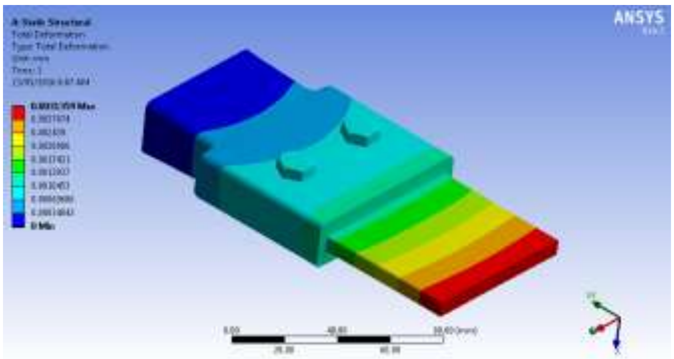


Figure 11: Total Deformation of protruded Bolted Joint

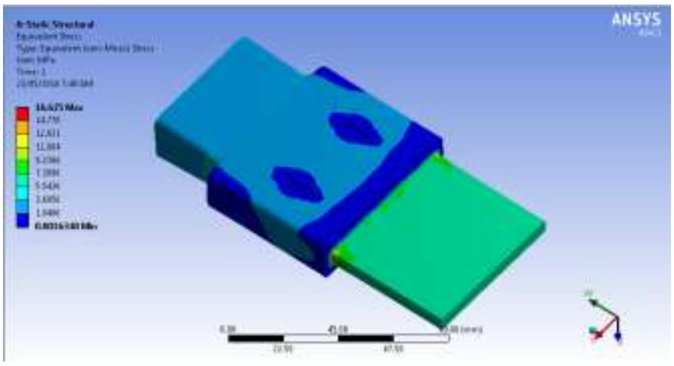


Figure 12: Equivalent Stress of Countersunk Bolted Joint

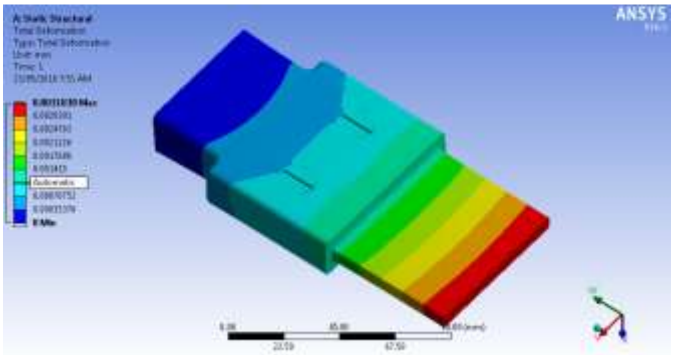


Figure 13: Total Deformation of Countersunk Bolted Joint

## V. EXPERIMENTAL VALIDATION

In this project work, we will be validating the strain/stress of the component by comparing results obtained from experimentation with results of analytical solution. Fix the spring on frame structure with the help of fixtures. Mount strain gauges on the spring. Loading on the spring shall be applied by means of screw jack and corresponding stress is recorded by using strain gauge. For measurement of strain, Wheatstone bridge network is used. The results for this work shall be validated through this Experimentation.

The force to the mono leaf composite spring is given by the pneumatic screw jack. The force given can be calculated as follows,

Where,

$d_1$ = bore diameter of cylinder= 100 mm

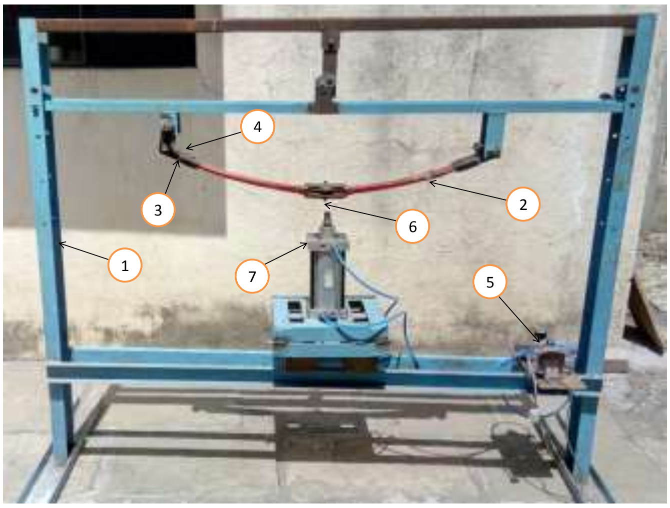
$d_2$= diameter of piston = 20 mm

p = applied pressure = 30 psi = 206.84 KPa

$$F = \frac{P\,\pi\,(d_1^2 - d_2^2)}{4}$$

$$F = \frac{0.20684 * \pi\,(100^2 - 20^2)}{4}$$

F = 1559.54 N




1. Frame, 2.Spring, 3.Strain gauges 4.Bolted Joint 5. Pneumatic circuit 6. Load cell 7. Screw Jack

Fig.14.Experimental Set up

Hence by solving we get the value of the load which we are giving to the leaf spring by the means of screw jack.

Fig.15.Mounting of Strain Guages

Further the strain guage rosette are attached to the digital strain indicator. By varying the load, the strain is being noted in a tabular form below,

Table 1: Strain Readings for Protruded Bolted configuration unit (μstrain)

| LOAD | POSITION | READING 1 | READING 2 |
|---|---|---|---|
| 70 | 2 | 2 | 2 |
| | 3 | -8 | -8 |
| | 4 | 381 | -376 |
| 60 | 2 | 2 | 2 |
| | 3 | -8 | -8 |
| | 4 | -370 | -375 |
| 50 | 2 | 2 | 2 |
| | 3 | -8 | -8 |
| | 4 | -372 | -365 |
| 40 | 2 | -2 | -2 |
| | 3 | -7 | -7 |
| | 4 | -367 | -367 |
| 30 | 2 | 2 | 2 |
| | 3 | -7 | -7 |
| | 4 | -341 | -340 |

Table 2: Strain Readings for Countersunked Bolted configuration unit (μstrain)

| LOAD | POSITION | READING 1 | READING 2 |
|---|---|---|---|
| 70 | 2 | 17 | 18 |
| | 3 | -24 | -24 |
| | 4 | -1089 | -1089 |
| 60 | 2 | 14 | 13 |
| | 3 | -21 | -21 |
| | 4 | -1013 | -975 |
| 50 | 2 | 10 | 10 |
| | 3 | -16 | -16 |
| | 4 | -759 | -758 |
| 40 | 2 | 7 | 7 |
| | 3 | -12 | -12 |
| | 4 | -575 | -550 |
| 30 | 2 | 3 | 3 |
| | 3 | -9 | -9 |
| | 4 | -446 | -475 |

The reading from the indicator is noted down. For the calculation of Stress, Hooke's law is used.

*Experimental Stress Calculations:*

*For Protruded Bolted Configuration:*

Following are the sample calculations for the Reading 1 at the load 0.482633 MPa (70 psi).

From reading 1,

For steel plates, we have,

$\epsilon_1 = 2$ μstrain and $\epsilon_2 = -8$ μstrain

$\epsilon_{eq} = \epsilon_1 + \epsilon_2 = 2 + (-8) = -6$ μstrain

$\epsilon_{eq} = -6 \times 10^{-6}$ strain

By Hooke's law,

$$\frac{Stress}{Strain} = E\ (young's\ modulus)$$

For steel plates, we have,

E= 210 GPa = 210000 MPa

Stress = E x Strain = 210000 x -6 x $10^{-6}$

Stress = -1.26 MPa (compressive)

For composite plate:

$\epsilon_1 = -381$ μstrain and E = 250000 MPa

By Hooke's law,

$$\frac{Stress}{Strain} = E\ (young's\ modulus)$$

We have,

Stress = E x Strain = 250000 x -381 x $10^{-6}$

Stress = -95.25 MPa (compressive)

*For Countersunked Bolted Configuration:*

Following are the sample calculations for the Reading 1 at the load 0.482633 MPa (70 psi).

From reading 1, we have, for steel plates,

$\epsilon_1 = 17$ μstrain and $\epsilon_2 = -24$ μstrain

$\epsilon_{eq} = \epsilon_1 + \epsilon_2 = 17 + (-24) = -7$ μstrain

$\epsilon_{eq} = -7 \times 10^{-6}$ strain

By Hooke's law,

$$\frac{Stress}{Strain} = E\ (young's\ modulus)$$

For steel plates, we have,

E= 210 GPa = 210000 MPa
Stress = E x Strain = 210000 x -7 x $10^{-6}$
Stress = -1.47 MPa (compressive)
For composite plate:
$\epsilon_1$ = -1089 µstrain and E = 250000 MPa
By Hooke's law,

$$\frac{Stress}{Strain} = E\ (young's\ modulus)$$

We have,
Stress = E x Strain = 250000 x -1089 x $10^{-6}$
Stress = -272.35 MPa (compressive)

Table 3: Stress Results for Protruded Bolted configuration (MPa)

| Load | Steel plates | | Composite plate | |
|---|---|---|---|---|
| | Reading 1 | Reading 2 | Reading 1 | Reading 2 |
| 0.482633 | -1.26 | -1.26 | -95.26 | -94 |
| 0.413685 | -1.26 | -1.26 | -92.5 | -93.75 |
| 0.344738 | -1.26 | -1.26 | -93 | -91.25 |
| 0.27579 | -1.05 | -1.05 | -91.75 | -91.75 |
| 0.206843 | -1.05 | -1.05 | -85.25 | -85 |

Table 4: Stress Results for Countersunked Bolted configuration (MPa)

| Load | Steel plates | | Composite plate | |
|---|---|---|---|---|
| | Reading 1 | Reading 2 | Reading 1 | Reading 2 |
| 0.482633 | -1.47 | -1.47 | -272.35 | -272.35 |
| 0.413685 | -1.47 | -1.47 | -253.25 | -243.75 |
| 0.344738 | -1.26 | -1.26 | -189.75 | -189.5 |
| 0.27579 | -1.26 | -1.26 | -143.75 | -137.5 |
| 0.206843 | -1.26 | -1.26 | -111.5 | -118.75 |

## VI. RESULTS AND DISCUSSIONS

From the experimental stress results, it can be observed that the stress concentration is prominent in the countersunk bolted configuration than the protruded bolted configuration.

For Steel plates, it is observed that about 15% the stress is increased in countersunk bolted configuration than protruded bolted configuration. For Composite plate, it is observed that about 65% the stress is increased in countersunk bolted configuration than protruded bolted configuration.

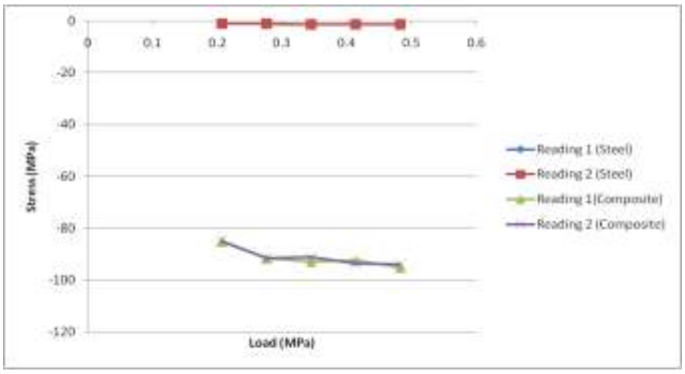



Figure 16: Graphical representation of Stress Results for Protruded Bolted configuration

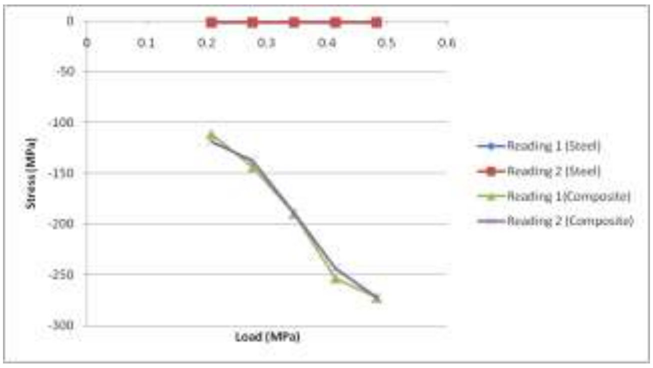



Figure 17: Graphical representation of Stress Results for Countersunked Bolted configuration

From the graphical representation, it is observed that the stresses in protruded bolted configuration is steadily increasing whereas in countersunked bolted configuration the stresses are rapidly increasing and may tend to early failure.

From the analytical approach, we are getting the stress concentration factors as follows,

For steel plates in protruded bolted configuration, we have

$K_t$ = 2.5.

For steel plates in countersunk bolted configuration, we have $K_t$ = 3.7337.

For composite plates, we have $K_t$ = 3.89265.

From the above results, we can say that the stress concentration in countersunk bolted configuration is more than protruded bolted configuration.

From the numerical approach, we are getting the stress values as shown in the result of Ansys Software. By observing, the results, we can say that the stress concentration is likely to be more in the periphery of countersunk bolted joints than protruded bolted joints. The stresses developed in the composite plates in countersunk bolted configuration are also likely to be more than the protruded bolted joints.

## VII. CONCLUSION

From the Analytical approach, it is observed that the stress concentration is likely to be more in countersunk bolted joints configuration than protruded bolted joints configuration. Similarly, from the numerical approach, it is observed that the stresses developed in the periphery of the countersunk bolted configuration are dominant than the former. The stresses developed in composite material also vary by the variation in the bolted joint configuration. It is observed that the stresses developed in the composite leaf spring having protruded bolted joint are less compared to leaf spring having countersunk bolted joint.

From the experimentation, we can say that the steel plates about 15% of the stress is increased in countersunk bolted configuration than protruded bolted configuration. And similarly for the composite part it is observed that 65% the stress is increased in countersunked bolted configuration than the former.

Finally it can be concluded that the use of composite leaf spring with protruded bolted joint is safer than the use of composite leaf spring with countersunked bolted joint.

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