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Structural Design and Analysis of Leaf Spring made of Composite Material

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Abstract: Modern Automobile industry has been facing increasing competition and innovations in the field of improving existing products. Redesigning conventional shapes and reducing weight while increasing or maintaining strength of existing products is becoming highly significant. Even tho leaves springs are the oldest form of suspension systems, most automobiles companies' use these same conventional leaf springs today also. Researches have proved that composite leaf springs can be used as a potential replacement for conventional metallic leaf springs because of their higher strength to weight ratio. In this paper we propose a new structurally modified trapezoidal composite leaf spring from conventional rectangular shaped steel leaf spring. For this purpose, a rectangular shaped rear leaf spring for MAHINDRA "MODEL-COMMANDER 650 DI" is considered. The objective is to compare the stresses, deformations and weight saving of trapezoidal composite leaf spring, rectangular composite leaf spring and rectangular steel leaf spring. The design constraint is stiffness. The composite material selected was glass fiber reinforced polymer (E-glass/epoxy). The design parameters were selected and analyzed with the objective of showing trapezoidal composite leaf spring was superior compared to rectangular composite leaf spring having same weight. Result shows that, the weight of rectangular composite leaf spring was nearly reduced up to 85% compared with steel material and newly proposed trapezoidal leaf spring was much superior to rectangular composite leaf spring. The leaf spring was modeled in SOLID WORKS and the analysis was done using ANSYS 16.0 software.
Keywords: Composite material, High strength to weight ratio, Trapezoidal leaf spring, Static Analysis, SOLID WORKS & ANSYS

I. INTRODUCTION

A. General Background

In automobile industry leaf spring has a major role, in 1970s in Europe and Japan and late 70's in America they put-forward the concept of front wheel drive, they used coil springs for suspension designs in automobile industry.Commercial vehicles such as vans and trucks,SUV uses leaf springs, and in railway carriages.One of the advantage of leaf spring in heavy vehicle is to spreading the load more widely over the vehicle's chassis, and coil springs transfer the load to a single point. Leaf springs are located at the rear axle which results in eliminating the need for trailing arms,which saves cost and weight in a rear axle suspension. The modern leaf springs implemented by adopting the parabolic shape. The adopted design is characterized by lesser number of leaves whose thickness changes from centre to ends following a parabolic curve. In this case,the design of inter-leaf friction is unnecessary, so the contact occurs only between the springs at both ends and the centre, where the axle is connected.by adopting parabolic springs can provide better riding comfort and not as "stiff" as conventional "multi-leaf springs". It is more often used on buses for better comfort. A leaf spring is a long, flat, thin, and flexible piece of spring steel or composite material that resists bending due to load. According to basic principles, the leaf spring design and assembly are comparatively easier, and leafs have been used in various load carrying capacities since ages. Now a days, most heavy duty vehicles commonly uses two sets of leaf springs per solid axle, which is mounted perpendicularly to withstand the weight of the vehicle.For light and heavy commercial vehicles, Semi-elliptic leaf springs are almost commonly used for suspension. The spring consists of a number of leaves called blades which are varying in length.An initial curvature is provided to the blades,so that they will tend to straighten under the action of load. The leaf spring is based upon the theory of a beam of uniform strength. The largest blade called main or master leaf, has eyes on both ends and the remaining blades are called graduated leaves. All the blades are arranged together by means of steel straps. The entire load of the vehicle is rests on the leaf springs, where it is mounted on the axle of the vehicles.The frame is connected to the front end with a simple pin joint, and the rear end of the spring is connected with a shackle. Shackle is a type of the flexible link which is used to connects rear eye of leaf spring and frame.The deflection of leaf spring occurs when the wheels moves up where there is a projection on the road surface which leads to changes the length between the spring eyes.The chassis of automobile is mounted on the axles in the form of springs to isolate the vehicle body from the road shocks such as bounce, pitch, roll or sway. These may leads to an uncomfortable ride and also cause additional stress in the automobile frame. The part which performs the function of isolating the automobile from the road shocks, is called a suspension system.

B. Objective

The objective of the present work is to design, analysis & optimization of leaf spring. Reducing weight while increasing or maintaining strength of products is getting to be highly important research issue in this modern world. This is done to achieve the following.

1) To the replace conventional steel leaf spring rectangular cross section with steel leaf spring trapezoidal cross section per leaf & whole leaf spring shape as a trapezoidal cross section by using same dimensions for all three cross sections.
2) To achieve substantial weight reduction in the suspension system by replacing all three cross section of leaf spring with composite leaf spring cross section
3) Find optimum cross section for leaf spring based on weight reduction & output parameters of leaf spring
4) Compare the load carrying capacity, stresses, deflection and weight savings of composite leaf spring for all cross section with that of cross section of steel leaf spring

C. Scope

The wide scope of composite material in automotive, aerospace, wind energy ,electrical, domestic purpose etc. Composite materials have a great potentiality of application in structures subjected to primarily to compressive load. Composite materials have attractive aspects like relatively high compressive strength, good adaptability in fabricating thick composite shells, low weight, low density and corrosion resistance. Composite materials have good mechanical, electrical, chemical properties, due to which we can use composite materials in various industries.

II. LITERATURE REVIEW

Raja manas machela et.al worked on Structural analysis is carried out in ansys by applying different materials one general material High carbon steel and two glass fibre material. From result table it is conclude that high carbon steel showing the least stress value and S2 glass fibre material showing least deformation values and explained the modeling and design of leaf spring, used in automobile suspension systems. Static analysis determines the safe stress and corresponding pay load of the leaf spring and also to study the behavior of structures under practical conditions. The present work attempts to analyze the safe load of the leaf spring, which will indicate the speed at which a comfortable speed and safe drive is possible.[1] Syam Babu Nulapathi et.al worked on Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. It carries lateral loads, brake torque, driving torque in addition to shock absorbing. The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device .According to the studies made a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The suspension leaf spring is one of the potential items for weight reduction in automobiles unsprung weight. This achieves the vehicle with more fuel efficiency and improved riding qualities. The introduction of composite materials was made impossible to reduce the weight.[2] M Ramalaxmi et.al worked on The dimensions of an existing conventional steel leaf spring of a Heavy commercial vehicle are taken as same dimensions of conventional leaf spring and are used to fabricate a composite multi leaf spring using R- Glass/epoxy, **S-** Glass epoxy and Carbon epoxy unidirectional laminates. In this project various leaf spring are designed and modelled using Mild steel, carbon epoxy, S-glass, and r-glass. Structural & modal analysis of composite Leaf spring is performed using ANSYS and for basic structural steel analysis is done by both CATIA and ANSYS software and compared. Leaf springs absorb the vehicle vibrations, shocks and bump loads (Induced due to road irregularities) by means of spring deflections, so that the potential energy is stored in the leaf spring and then relieved slowly . Ability to store and absorb more amount of strain energy ensures the comfortable suspension system. Many suspension systems work on the same principle including conventional leaf springs. However, for the same load and shock absorbing performance, conventional (steel) leaf springs use excess of material making them considerably heavy. This can be improved by introducing composite materials in place of steel in the conventional spring. [3] Dr Rabindra Nath Barman et.al In the present work, the multi-leaf spring is modelled in CATIAand the same were analysed in the static structural domain of ANSYS software . The result were discussed in the preceding section and it is concluded that,for the given design specifications,the maximum bending stresses for three different loading conditions are well ithin the safe limit.For the maximum load of 15000 N ,the stress value as lower than that of the alooable stress of 66.67 Mpa for a factor of safety 1.5 . we further conclude that ,stresses in the extra full length leaves were almost 50% more than that of the graguated length leaves .Finally the present ork offers an exclusive idea regarding the construction of muli-leaf spring through its proposal for manufacturing the extra full-length leaves with composite ,while using steel for the rest of the leaves ,to minimise the cost.[4]

III.METHODOLOGY

A. Numerical Calculations

Model-Mahindra"Model-Commander 650 Di"
Number of leaf springs = 10 ,Overall length of the spring = 2L1 = 115cm = 1150 mm
Width of leaves = 50 mm
Assuming factor of safety =1.33
Number of full length leaves = 2 = Nf
Number of graduated leaves = 8 = Ng
Number of springs = 10 = (Ng+Nf)
Center load = 2W =1910 kg
2W =1910 X 10 X 1.33 is nearly 25403 N
2W = 25403/4 = 6350.7 N
2W= total load/no of springs = 6350.7 N
Effective length =1120 mm, ineffective length = 90 mm, no of full length leafs =2 ,
gradual length leafs = 8, Total leafs =10
length of smallest leaf(leaf 1)= (1120/10-1)+90 = 214 mm
length of leaf 2= (1120/10-1)×2+90=338 mm
length of leaf 3= (1120/10-1)×3+90= 463 mm
length of leaf 4= (1120/10-1)×4+90=588 mm
length of leaf 5 = (1120/10-1)×5+90=712 mm
length of leaf 6 = (1120/10-1)×6+90=837 mm
length of leaf 7= (1120/10-1)×7+90=961 mm
length of leaf 8= (1120/10-1)×8+90=1085 mm
length of leaf 9= 1120 mm
length of leaf 10= 1120 mm
For steel,
Weight of smallest leaf (leaf 1) = density × volume× acceleration due to gravity
= 214 × 6 × 50 × 0.00000786 ×10
= 5.046 N
Weight of leaf 2 = 338 × 6 × 50 × 0.00000786 ×10
=7.97N
Weight of leaf 3 = 463 × 6 × 50 × 0.00000786 × 10
=10.91N
Weight of leaf 4 = 588 × 6 × 50 × 0.00000786 × 10
=13.86N
Weight of leaf 5 = 712 × 6 × 50 × 0.00000786 × 10
= 16.78N
Weight of leaf 6 = 837 × 6 × 50 × 0.00000786 × 10
= 19.73N
Weight of leaf 7 = 961 × 6 × 50 × 0.00000786 × 10
= 22.66N
Weight of leaf 8= 1085 × 6 × 50 × 0.00000786 × 10
= 25.58N
Weight of leaf 9 = 1120 × 6 × 50 × 0.00000786 × 10
=26.40N Weight of leaf10 = 26.40N
Total weight of steel leaf spring = 175.336N For Eglass/epoxy,

Weight of mono leaf spring = 1120 × 24 × 50 × 0.000002 × 10
= 26.88N Weight saved = 175.336 – 26.88 = 148.456N
%weight saved = (148.456 ÷ 175.336) × 100
= 84.66%
Equalizing the volume of Trapezoidal leaf spring and Rectangular leaf spring
Since length of the leaves are same, we can exclude the in both sides.
(a+b)/2×h = xy

Where ,
a = Width of smaller end of trapezoidal leaf
b = Width of larger end of trapezoidal leaf
h =height
x = width of rectangular leaf
y = thickness of rectangular leaf

Taking h=80 mm
Given x=50 mm , y=60 mm
a+b/2×80=50×60
a+b=75 -----1
But b/a=60/55=1.091
b = 1.091×a
2.091a=75
a = 35.868 mm
b = 1.091×a
b = 39.1319 mm

B. *Material for Leaf Spring*

The material used for leaf springs is usually a plain carbon steel having 0.90 to 1.0% carbon. The leaves are heat treated after the forming process. The heat treatment of spring steel products has greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties.

1) Carbon/Graphite fibers: Their advantages include high specific strength and modulus, low coefficient of thermal expansion and high fatigue strength. Graphite, when used alone has low impact resistance.Its drawbacks include high cost, low impact resistance and high electrical conductivity.
2) Glass fibers: The main advantage of Glass fiber over others is its low cost. It has high strength, high chemical resistance and good insulating properties. The disadvantages are low elastic modulus poor adhesion to polymers, low fatigue strength and high density, which increase leaf spring weight and size. Also crack detection becomes difficult.
3) Composite materials: A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties. However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other.
4) Natural composites: Natural composites exist in both animals and plants. Wood is a composite – it is made from long cellulose fibres (a polymer) held together by a much weaker substance called lignin. Cellulose is also found in cotton, but without the lignin to bind it together it is much weaker. The two weak substances – lignin and cellulose – together form a much stronger one. The bone in your body is also a composite. It is made from a hard but brittle material called hydroxyapatite (which is mainly calcium phosphate) and a soft and flexible material called collagen .

C. *Making Composites*

Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibres or fragments of the other material, which is called the reinforcement.

D. *Composite Leaf Springs*

Composites are well suited for leaf-spring applications due to their high strength-to-weight ratio, fatigue resistance and natural frequency. Internal damping in the composite material leads to better vibration energy absorption within the material, resulting in reduced transmission of vibration noise to neighboring structures. The biggest benefit, however, is mass reduction: Composite leaf springs are up to five times more durable than a steel spring, so when General Motors (GM, Detroit, Mich.) switched to a glass-reinforced epoxy composite transverse leaf spring (supplied byLiteflex LLC, Englewood, Colo.) on the 1981 Chevrolet, a mono-leaf composite spring, weighing 8 lb/3.7 kg, replaced a ten-leaf steel system that weighed 41 lb/18.6 kg. This reportedly enabled GM to shave 15 kg/33 lb of unsprung weight , yet maintain the same spring rates. The leaf spring was transverse-mounted; that is, it ran across the car's width at each axle.

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TABLE I
MECHANICAL PROPERTIES OF STEEL

Mechanical	Symbols	Units	Values
Young s Modulus	E	Gpa	207
Shear Modulus	G	Gpa	80
Poissons ratio	μ		.3
Yield strength	Sy	Mpa	370
Density	ρ	Kj/m ȝ	7600

TABLE II
PROPERTIES OF COMPOSITE MATERIALS

Sl No	Properties	Eglass/Epoxy
1	EX (Mpa)	43000
2	EY(Mpa)	6500
3	E(Mpa)	6500
4	PRXY	0.27
5	PRY	0.06
6	PRX	0.06
7	GX(MPA)	4500
8	GY(MPA)	2500
9	G(MPA)	2500
10	P	0.000002

E. Design

The leaf spring model was done in SOLID WORK software.This work deals with replacement of cross section of rectangular steel leaf spring of a light commercial vehicle with cross section of trapezoidal per leaf & whole shape as a trapezoidal cross section. Numerical calculations are completed with the help of design equations of spring. Dimension of trapezoidal cross section per leaf & trapezoidal cross section are to be taken as same dimension of rectangular cross section of leaf. Different Material had been used for trapezoidal cross section per leaf & trapezoidal cross section & compare with each other .The modeling of the leaf spring have been done in SOLIDWORK. Finite element analysis of the leaf spring have been carried out in ANSYS 16.

TABLE III
LEAF SPRING PARAMETERS

Leaf No:	Full leaf length (mm)	Radius of curvature
1	1120	961
2	1120	967
3	1085	973
4	961	979
5	837	985
6	712	991
7	588	997
8	463	1003
9	338	1009
10	214	1015

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1) *Sketching*: *To create a line in a 3D sketch:*

a) Click 3D Sketch (Sketch toolbar) or Insert > 3D Sketch.
i) In new parts, the view changes to Isometric.
b) Click Line (Sketch toolbar) or Tools > Sketch Entities > Line.
c) In the PropertyManager, under Options, select one of the following:
i) For construction to create a 3D construction line.
ii) Infinite length to create a 3D line of infinite length.
iii) Midpoint line to create a line that is symmetrical from the midpoint of the line.
d) Click in the graphics area to start the line.
i) The 3D Line PropertyManager appears and the pointer changes to XY.
ii) Each time you click, the space handle appears to orient your sketch.
iii) If you want to change planes, press Tab.
iv) Drag to where you want the line segment to end.
v) To continue the line, select the end point and press Tab to change to another plane if necessary.
vi) Drag the second segment and release the pointer.

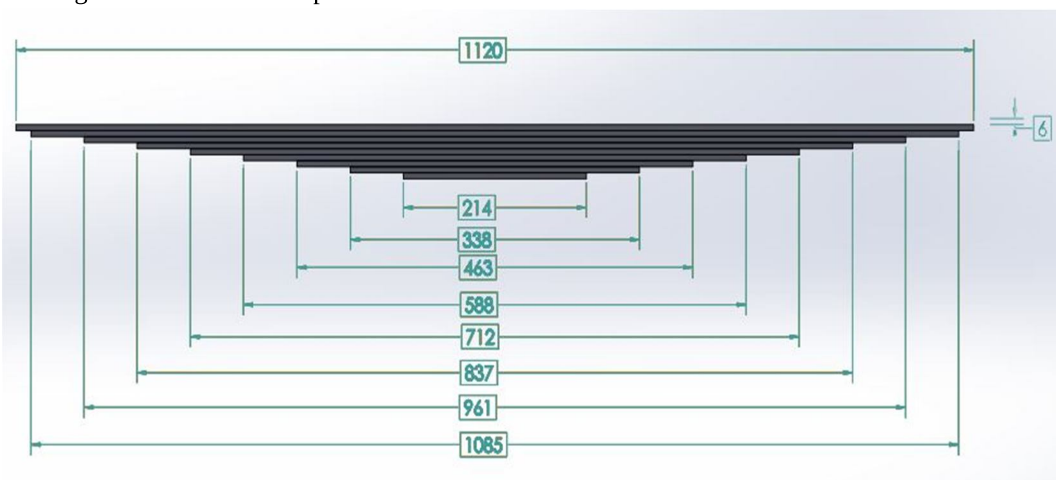

Figure 1. Assembled model of leafspring developed in solidwork

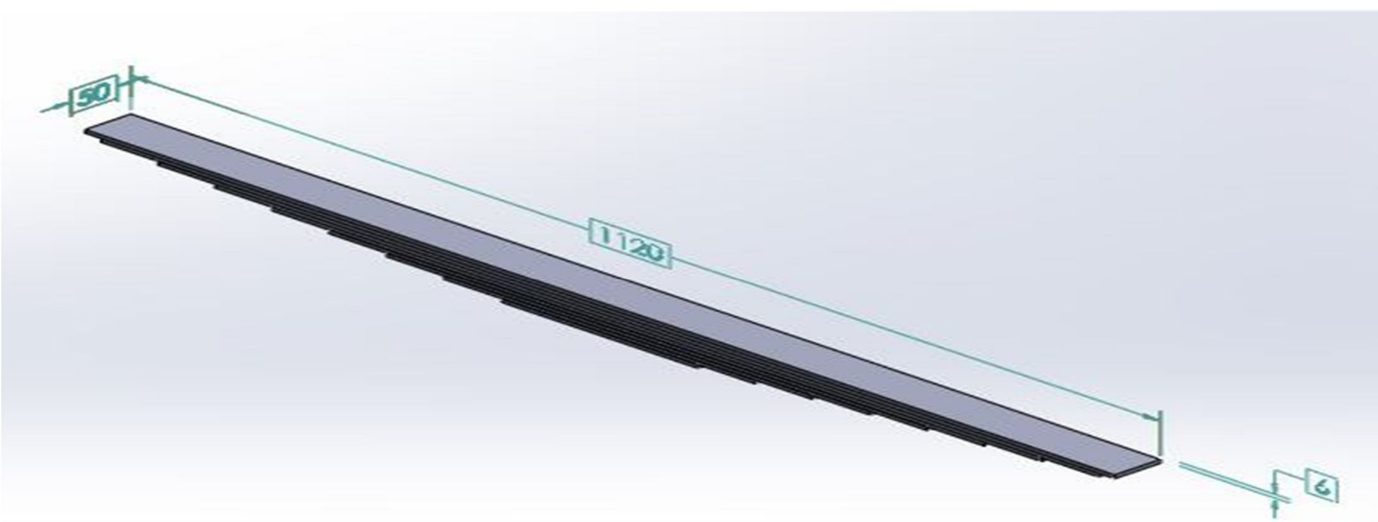

Figure 2. 3D Model

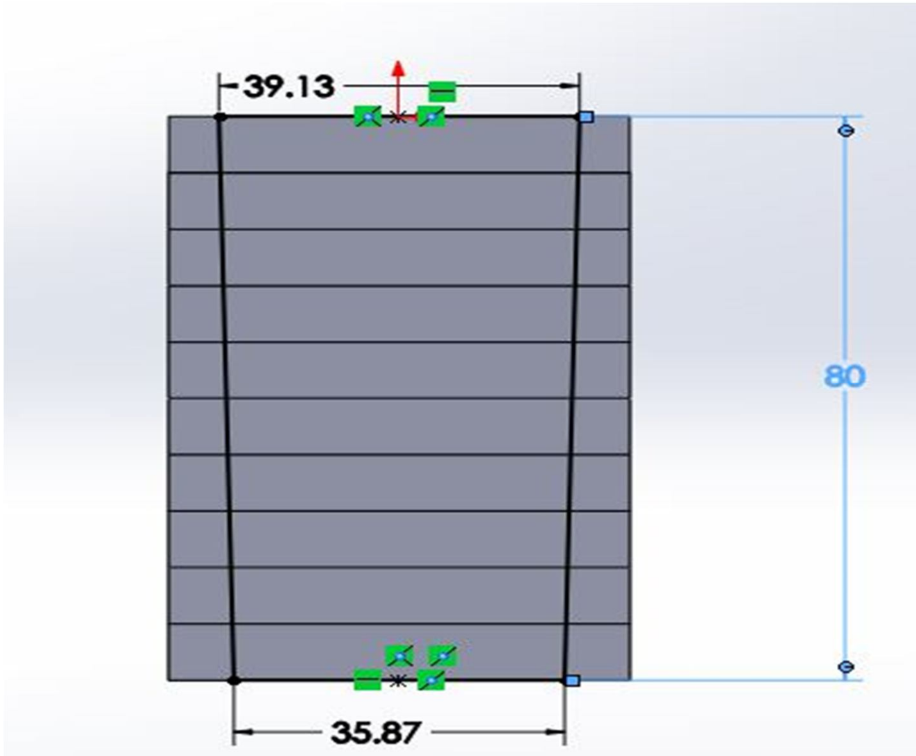

Figure 3. TrapeZoidal cross section

By using 60/55 cross section its found that, value of stress & displacement is nearer to rectangular cross section . It also found from result that as value of width increased its result in decreasing value of stress & deflection. So proper cross section for leaf spring is selected 60/55.

F. Analysis

The analysis is done in ANSYS 16.0, the analysis is the limitation of the operation of practical conditions, The boundary conditions and loading conditions are entered in the ansys platform. From the Finite element analysis the normal and shear stress of each points under the different loading conditions are obtained.The software implements equations that govern the behaviour of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated, or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand.This enables a reduction in the level of risk, and in the cost of ineffective designs. The multifaceted nature of ANSYS also provides a means to ensure that users are able to see the effect of a design on the whole behaviour of the product.

1) *Process In Ansys:*
   a) Build Geometry: *Construct a two or three dimensional representation of the object to be modeled and tested using the work plane coordinate system within ANSYS.*
   b) Define Material Properties: Now that the part exists, define a library of the necessary materials that compose the object(or project) being modeled. This includes thermal and mechanical properties.
   c) Generate Mesh: At this point ANSYS understands the makeup of the part. Now define how the modeled system should be broken down into finite pieces.
   d) Apply Loads: Once the system is fully designed, the last task is to burden the system with constraints, such as physical loadings or boundary conditions.
   e) Obtain Solution: This is actually a step, because ANSYS needs to understand within what state (steady state, transient… etc.) the problem must be solved.
   f) Present the Results: After the solution has been obtained, there are many ways to present ANSYS' results, choose from many options such as tables, graphs, and contour plots.

2) *Static Analysis:* Used to determine displacements, stresses, etc. under static loading conditions. ANSYS can compute both linear and nonlinear static analyses. Nonlinearities can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces, and creep.

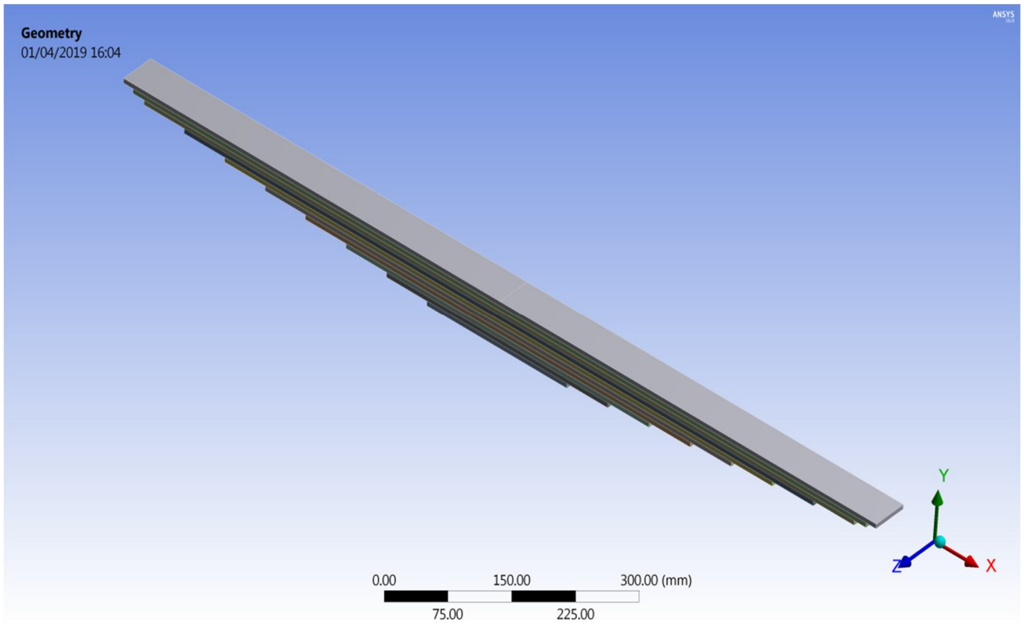

Figure 4. Leaf spring modelled in Ansys

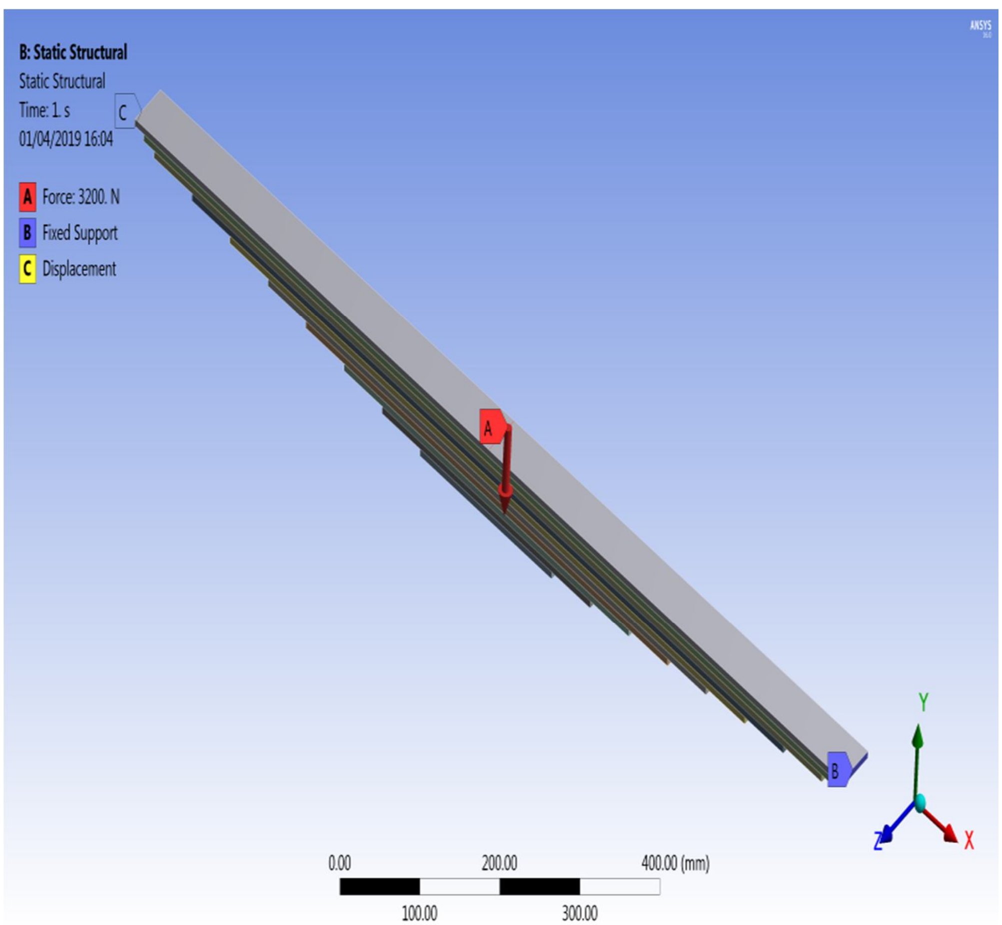

Figure 5. Loads & boundry conditions

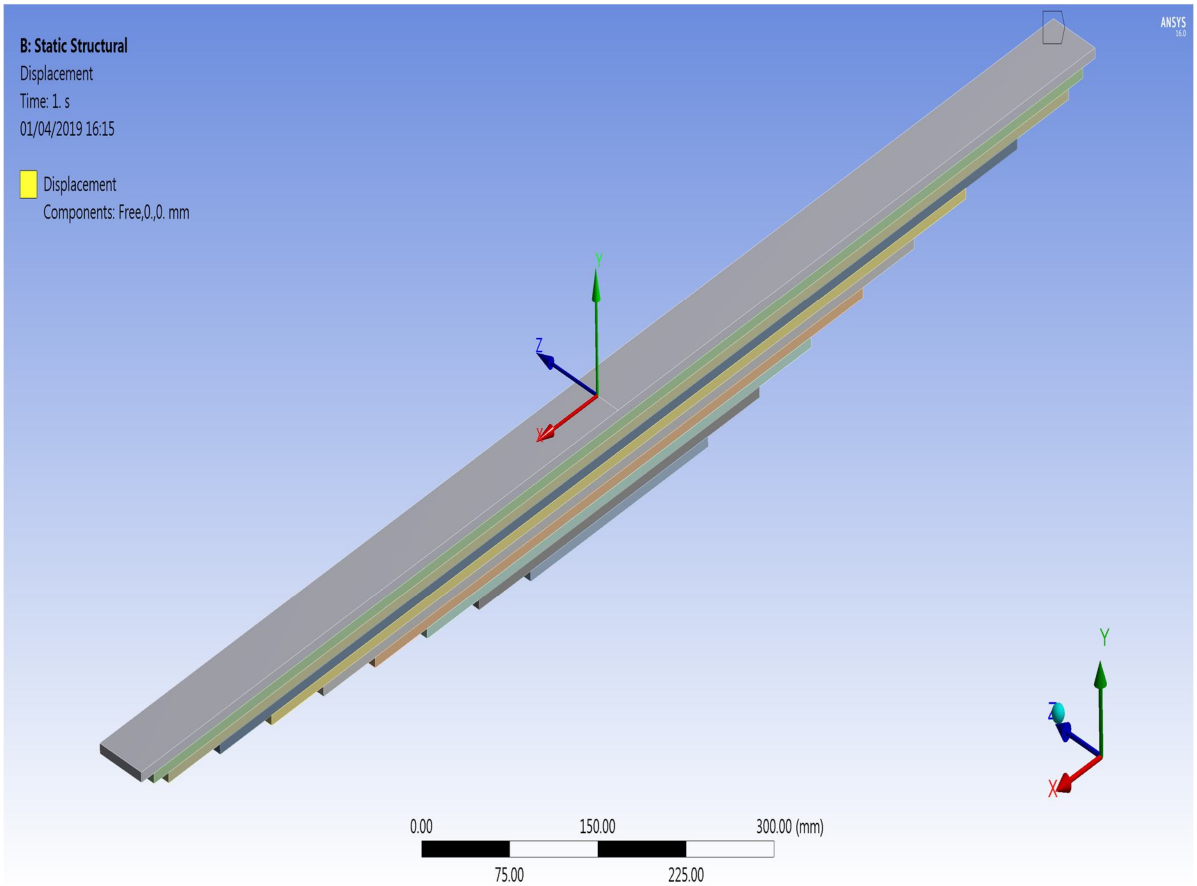

Figure 6. Displacement boundary conditions

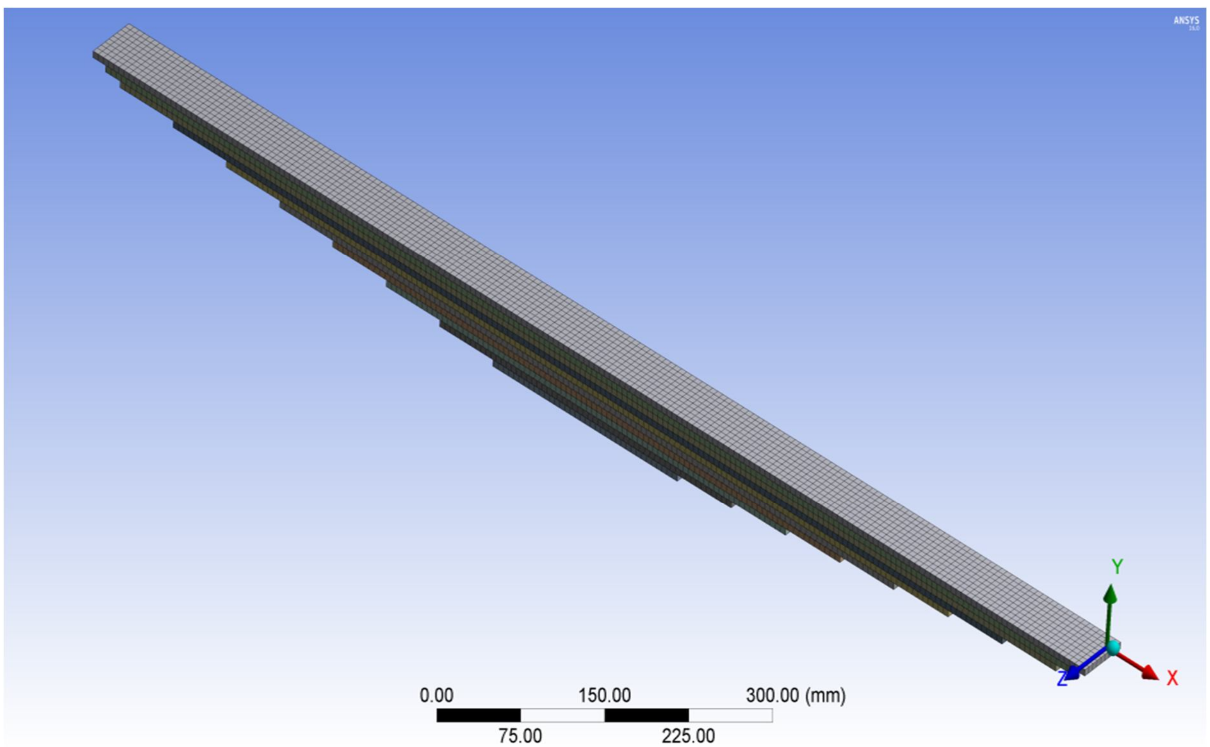

Figure 7. Displacement boundary conditions

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IV. RESULT AND DISCUSSION

A. Analysis Results

1) For Steel

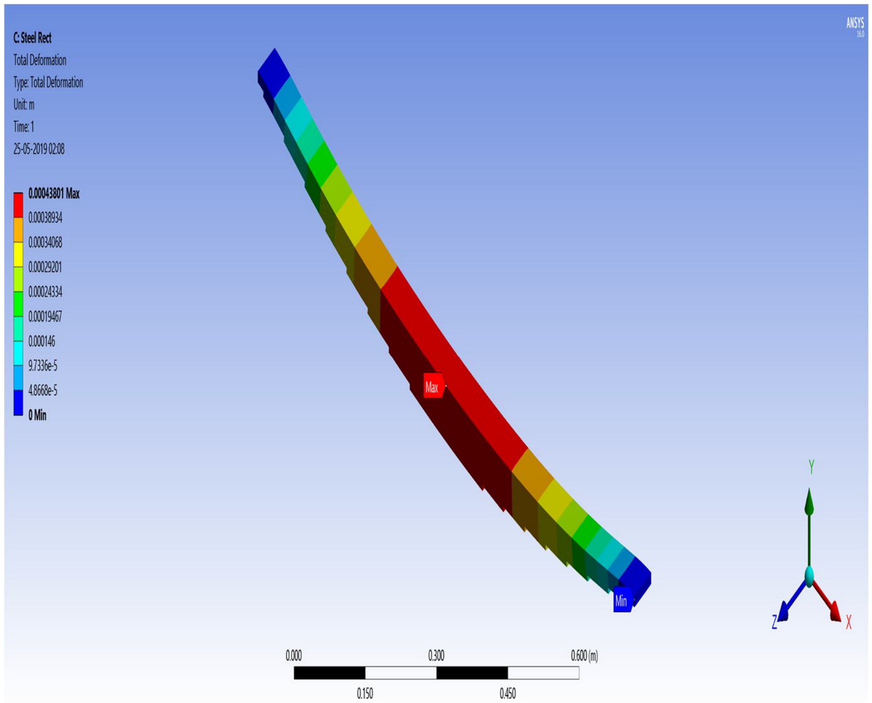

Figure 8. Deformation on steel

Values of Deformation
Maximum: 0.0004301m

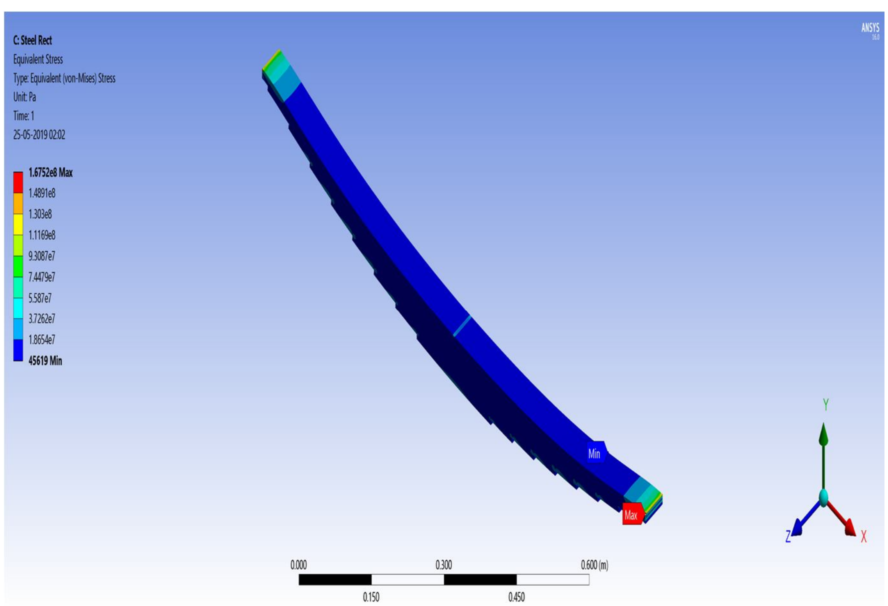

Figure 9. Equivalent stress

Values of Equivalent stress
Maximum: 1.6757×10^8Pa

3) For E-Glass Epoxy

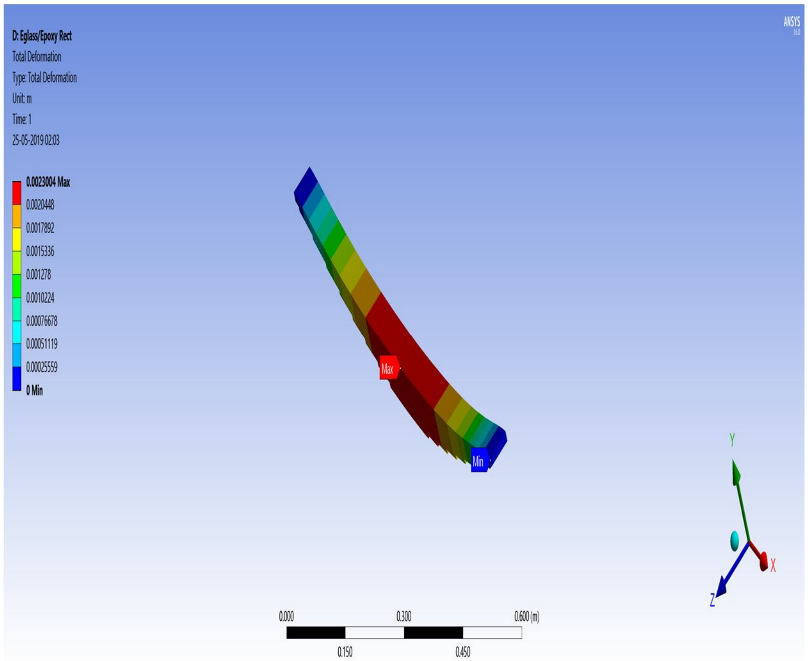

Figure 10. Deformation on E-GLASS EPOXY

Value of Deformation on E-GLASS EPOXY
Maximum: 0.0023004m

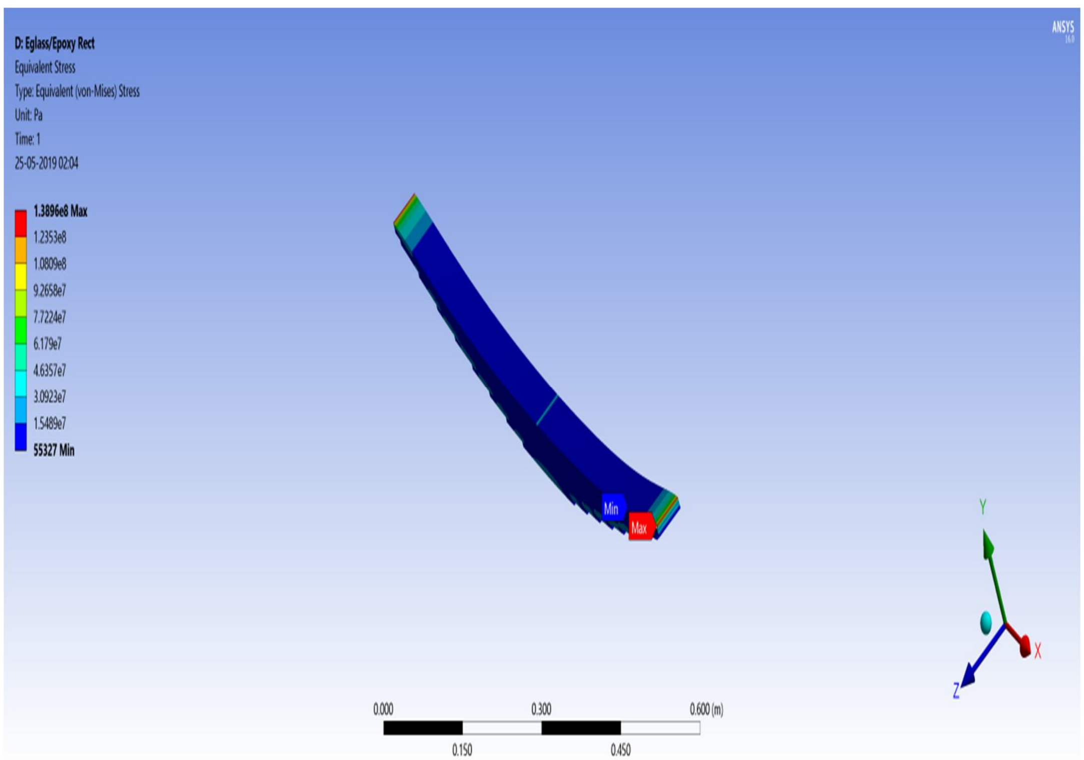

Figure 11. Equivalent stress

Value of Equivalent Stress
Maximum 1.3896×10^{8}Pa

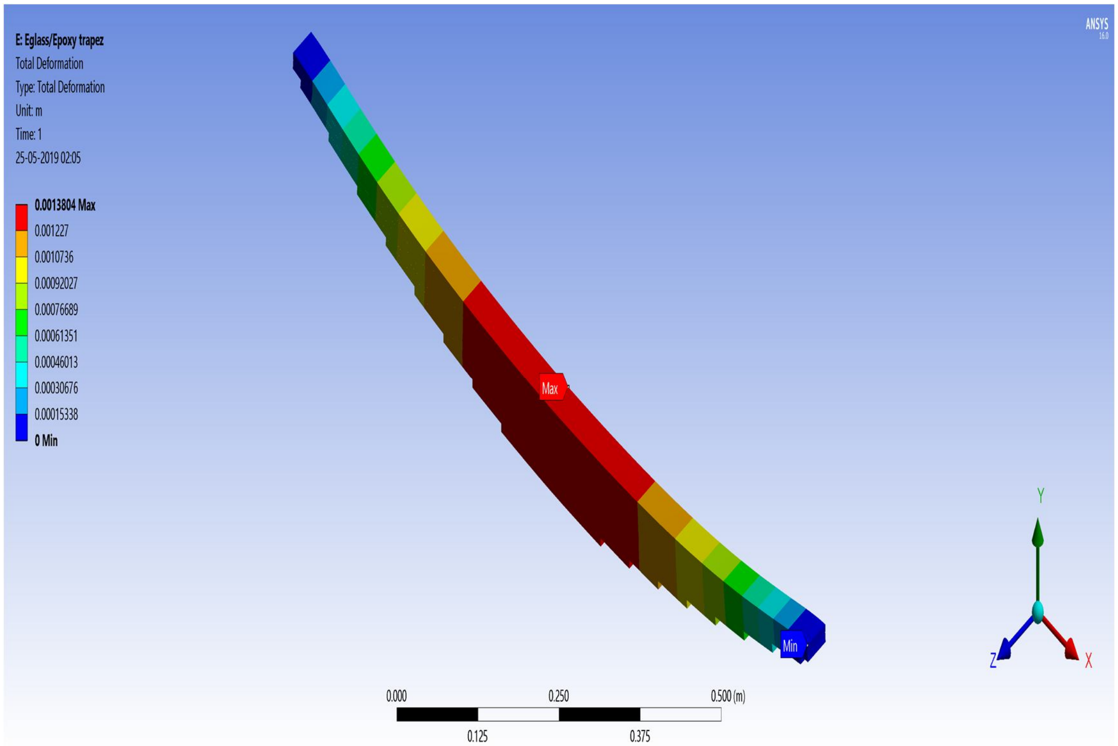

Figure 12. Deformation on trapezodial shape [E-GLASS EPOXY]

Value of deformation on trapezoidal shape
Maximum 0.00013804m

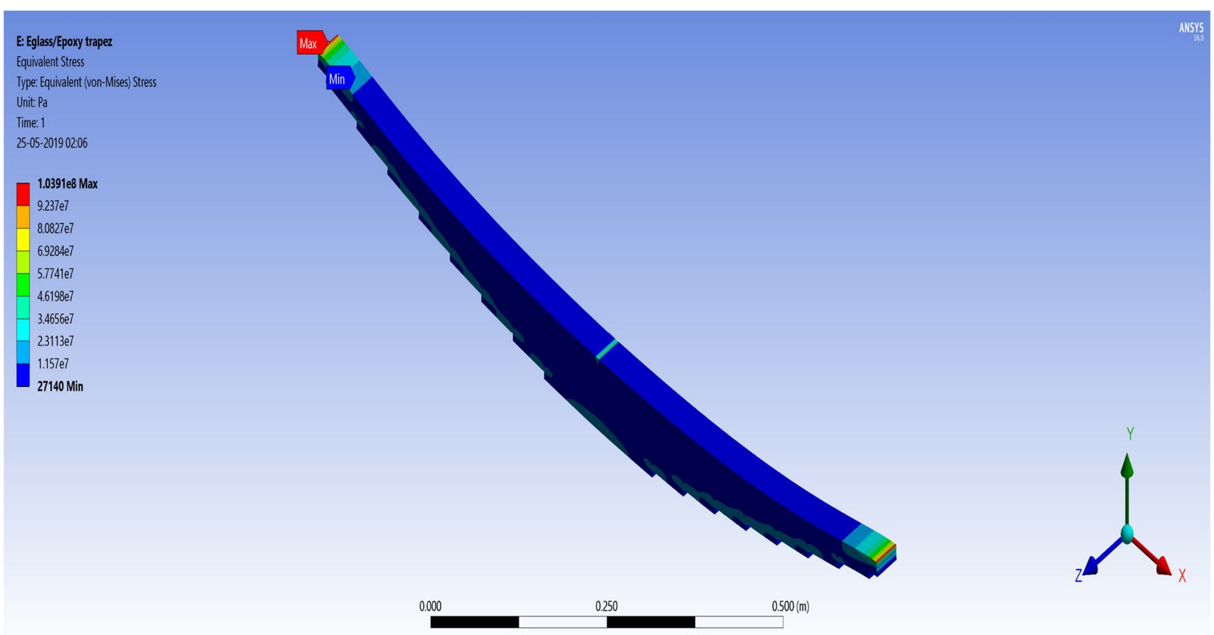

Figure 13 Equivalent stress

Value of Equivalent stress
Maximum 1.0391×10^{8}Pa

TABLE 4.
RESULT ANALYSIS

Cases	Deformation (m)	Equivalent Stress (Pa)
Conventional steel leaf spring	0.0004301	1.6757×10^{8}
E-glass/Epoxy leaf spring	0.0023004	1.3896×10^{8}
E-glass/Epoxy leaf spring of trapezoidal shape	0.0013804	1.0391×10^{8}

V. CONCLUSION

A. From static analysis results, it is seen that maximum von misses stress for a given load of 3200N for steel leaf spring of rectangular cross section is 1.6757×108 Mpa and maximum deformation is .0004301m.

B. From static analysis it's found that by using E-glass/Epoxy for a given load of 3200N on rectangular cross section leaf , maximum von mises stress is 1.3896×108 Pa and maximum deflection is 0.0023004m.

C. From static analysis it's found that by using E-glass/Epoxy for a given load of 3200N on trapezoidal cross section maximum von mises stress is 1.0391×108 Pa and maximum deflection is 0.0013804mm.

D. All the FEA results are compared with the theoretical results and it is found that they are within the allowable limits and nearly equal to the theoretical results.

E. From static analysis it is observed that by using trapezoidal cross- section leaf spring are better when compared with rectangular cross-sectional leaf spring.

VI. ACKNOWLEDGMENT

Presentation, inspiration and motivation have always played a key role in the success of any venture. First of all we would like to thank God, the almighty for his kind blessings upon us for the completion of this project work.We express our sincere thanks to all the faculty members of mechanical engineering department for their valuable guidance and kind supervision.We surrender our esteemed and sincere thanks to all the faculty members of mechanical engineering department for their help and timely suggestion. We are thankful to our parents and friends for their motivation and support.

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