Modeling and Finite Element Analysis of Hybrid FRP Leaf Spring

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Abstract - *In this paper, static stress and modal analysis of hybrid Fibre Reinforced Polymer (FRP) leaf spring made of carbon fibre and Epoxy Resin with different fibre layers, different fibre orientations has been carried out using FE analysis. Primary objective is to find out alternative material for leaf spring, other than conventional available material of spring steel. FRP material has high strength to weight ratio as compared to conventional available material of spring steel. Using FRP material for construction of leaf spring, weight of leaf spring has been reduced. Resonance of leaf spring with excitation frequency due to road roughness can be avoided because FRP material has high natural frequency. A model of the FRP leaf spring has been formulated. FRP modelling of leaf spring has been carried out in ANSYS composite prepost. Modal analysis of the FRP leaf spring under consideration has been carried out to determine first few natural frequencies and corresponding mode shapes to ensure that resonance of the leaf spring has been avoided.*

Key Words: Hybrid FRP, Leaf Spring, FEA, Carbon fibre/ Epoxy, ANSYS, Modal Analysis, Static Stress Analysis.

1. INTRODUCTION

Originally leaf spring, sometimes called as laminated or carriage spring, is a simple form of spring, commonly used for the suspension in wheeled vehicles. A leaf spring can either be attached directly to the frame at both ends or attached directly at one end, usually the front, with the other end attached through a shackle, a short swinging arm. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus provides for softer springiness. [1] Leaf spring is potential item to reduce weight of the vehicle in order to economize energy. [2] Application of FRP material to leaf spring, reduce weight of the spring without reduction in stiffness and load carrying capacity of leaf spring. Strength of fiber depends upon orientation angle of fibers. By using different fibre angles for different layers of leaf spring, we can get required amount of stiffness with less number of layers.

In the present work, leaf spring has been modelled in 10 layers. Each layer has different fiber orientation. Modelling of FRP has been carried out in ANSYS composite prepost. Finite element analysis has been carried out in ANSYS workbench. Stress Distribution in each layer has been plotted by using ANSYS composite prepost. Modal analysis of leaf spring has been carried out to find out fundamental natural frequency of leaf spring. In order to have good ride comfort, natural frequency of leaf spring should be greater than road excitation frequency due to road roughness.

2. MODELLING OF FRP IN ANSYS COMPOSITE PREPOST

FRP modelling for leaf spring has been carried out in ANSYS composite prepost. FRP leaf spring has following specifications: Leaf spring total length, 1170 mm; Leaf width, 64 mm; Total number of layers, 10; Thickness of each layer, 2 mm; Fibre angles used, 0, 45,-45,90 degree. [1] Materials used for leaf spring; Epoxy- Carbon Fibre and Resin Epoxy. Ply layer numbers and their corresponding ply angles are as shown in Table 1. Figure 1 shows model of FRP leaf spring in ANSYS composite prepost

Table -1: Ply Layer Number and Ply Angle

Ply layer number (From bottom to top)	Ply angle (Degree)
Modelling ply1	0
Modelling ply 2	0
Modelling ply 3	45
Modelling ply 4	-45
Modelling ply 5	45
Modelling ply 6	-45
Modelling ply 7	45
Modelling ply 8	-45
Modelling ply 9	90
Modelling ply 10	90

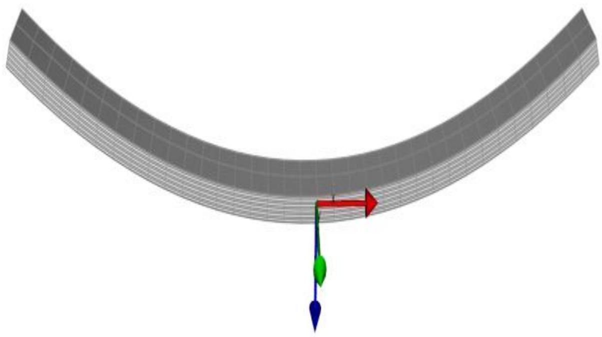

Fig -1: ANSYS Model of the FRP Leaf Spring

3. MODELLING OF FRP LEAF SPRING IN ANSYS COMPOSITE PREPOST

Fibers with different orientations are modelled in ANSYS composite prepost. Red color axis denotes X-axis, green color axis denotes Y-Axis and blue color axis denotes Z- axis. Yellow color axis is used as reference axis. Fibre angles of 0, 45, -45, 90 degree are used for modeling in ANSYS composite Prepost.

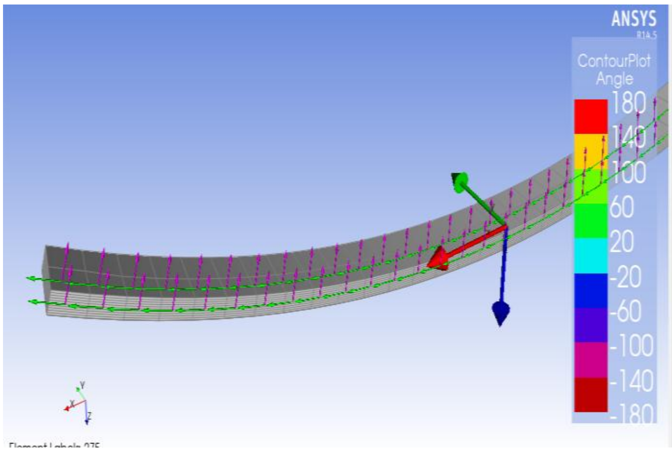

Fig -2: Modelling Ply with Fibre Angle of 0°

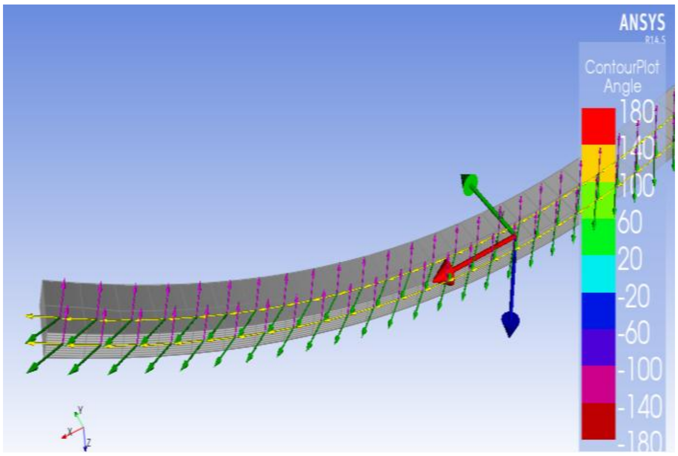

Fig -3: Modelling Ply with Fibre Angle of 45°

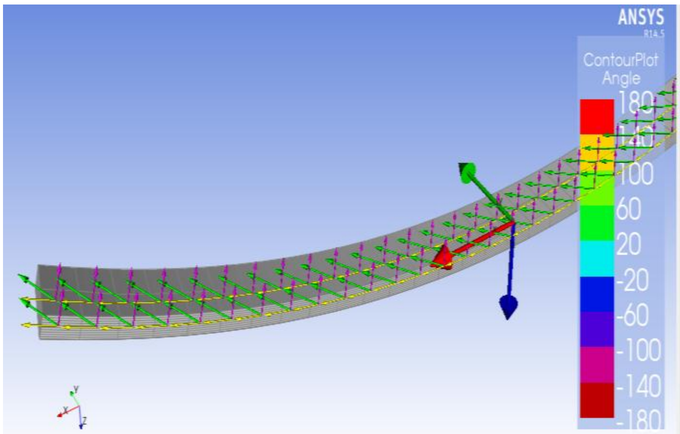

Fig -4: Modelling Ply with Fibre Angle of -45°

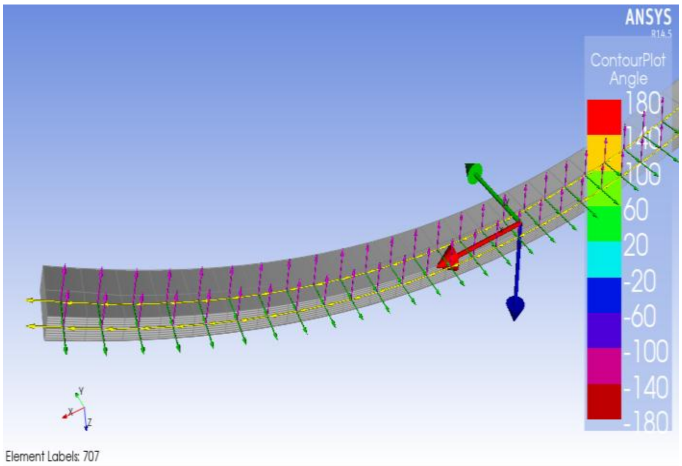

Fig -5: Modelling Ply with Fibre Angle of 90°

4. ALGORITHM USED FOR STATIC STRESS ANALYSIS OF FRP LEAF SPRING

ANSYS composite prepost and ANSYS workbench are used for static stress analysis of FRP leaf spring. Figure 6 shows algorithm used for static stress analysis of FRP leaf spring. FRP modelling of leaf spring has been carried out in ACP pre and static stress analysis is carried out in ANSYS workbench and results of static analysis are viewed in ACP post.

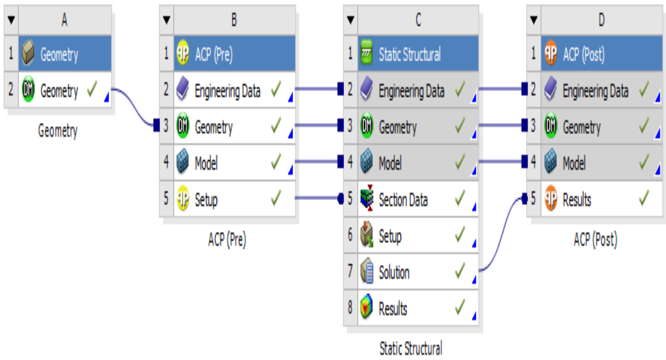

Fig -6: Algorithm used for Static Stress Analysis of FRP Leaf Spring

5. STATIC STRESS ANALYSIS OF LEAF SPRING

Static stress analysis has been carried out to find out deformation and stress in FRP leaf spring. Stress distribution in each layer of leaf spring has been found out.

5.1 Meshed Model of FRP Leaf Spring

Meshing involves dividing full model into discrete number of elements. Free meshing has been selected because leaf spring includes end sharp curves. [3]Meshed model of leaf spring is shown in figure 7.

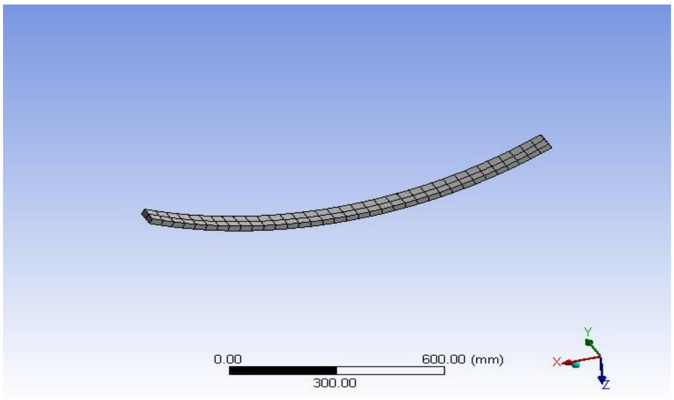

Fig -7: Meshed Model of FRP Leaf Spring

5.2 Leaf Spring Boundary Conditions

Front eye of leaf spring is provided with revolute joint which permits only rotation about Y-axis. Rear eye of leaf spring is attached to the shackle which permits rotation about Y-axis and translational movement along X-axis. Figure 8 shows the boundary conditions of the FRP leaf spring.

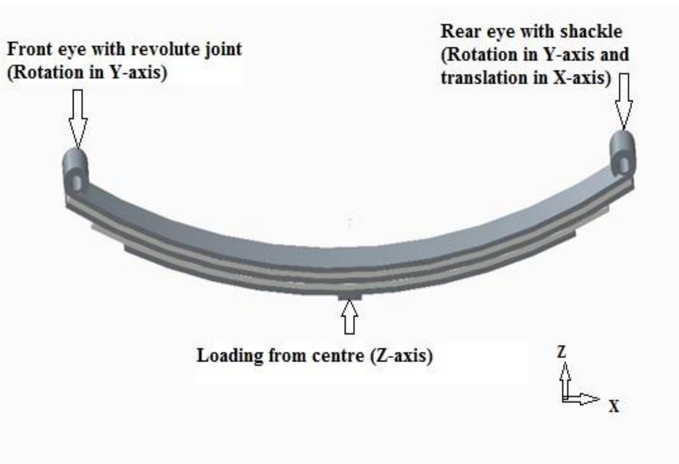

Fig -8: Leaf Spring Boundary Conditions [1]

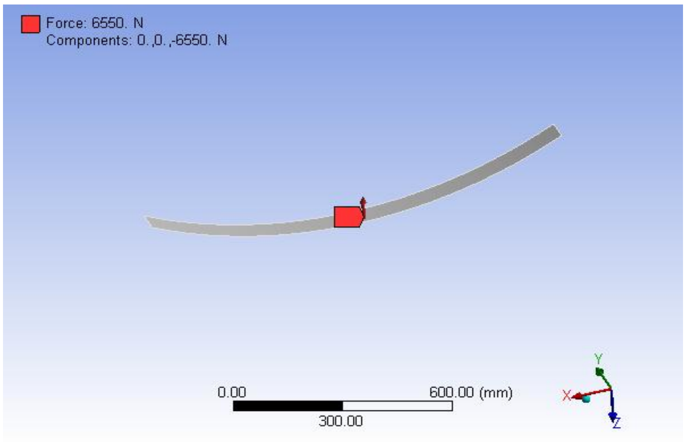

Fig -9: Static Loading of 6550 N

5.3 Static Stress Analysis Results of FRP Leaf Spring

Gross weight of the vehicle is 25702.2 N. [1] For each leaf using (quarter car), the static load of 1/4th of gross weight of 6550 N is applied at the middle of the leaf spring. Boundary conditions are applied to both ends of the steel leaf spring. Maximum deformation and equivalent stress in leaf spring are given in figure 10 and figure 11.

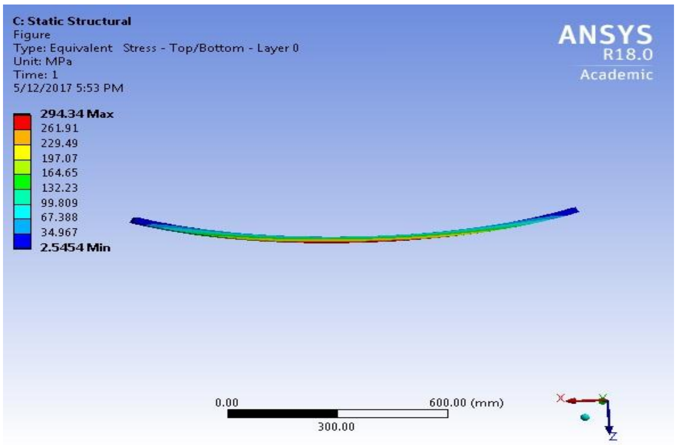

Fig -10: Equivalent Stress Plot of FRP Leaf Spring

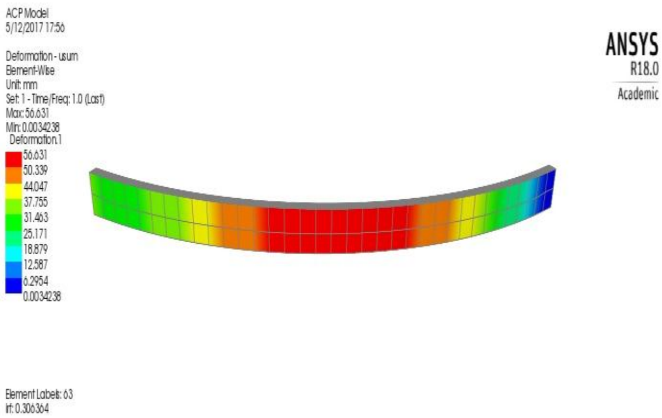

Fig -11: Deformation Plot of Leaf Spring

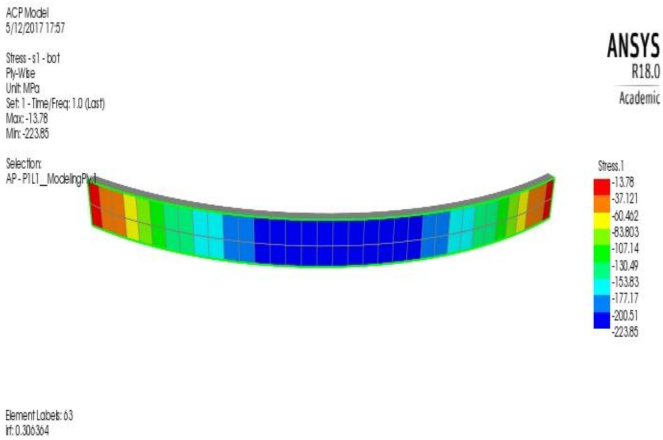

Fig -12: Stress Distribution in layer 1 of Leaf Spring

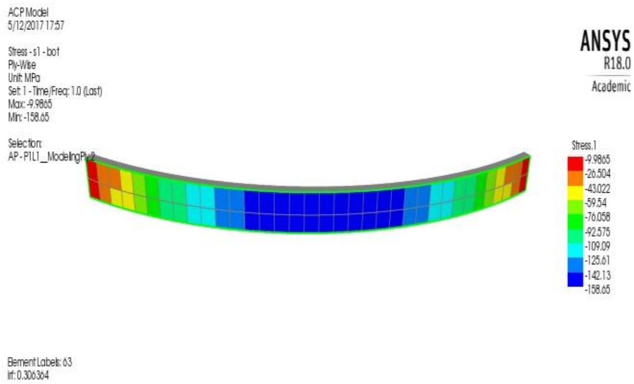

Fig -13: Stress Distribution in layer 2 of Leaf Spring

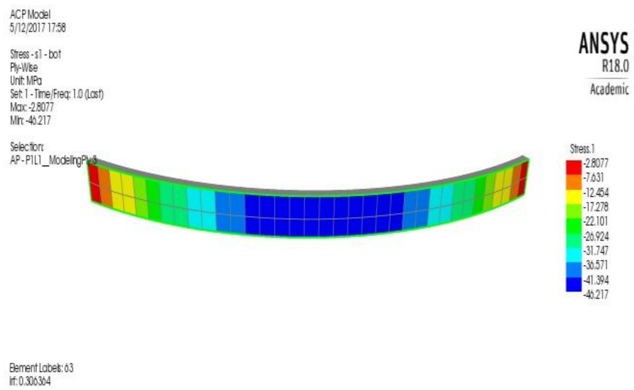

Fig -14: Stress Distribution in layer 3 of Leaf Spring

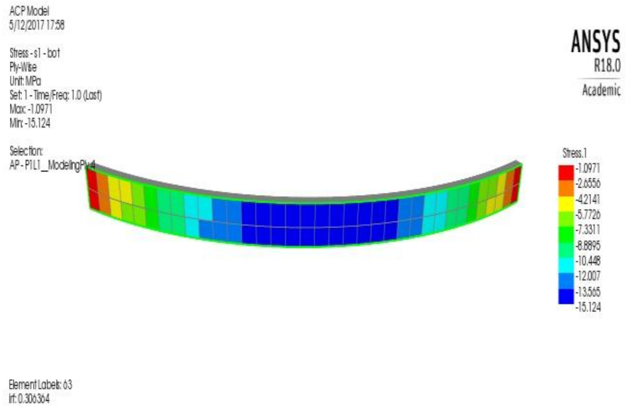

Fig -15: Stress Distribution in layer 4 of Leaf Spring

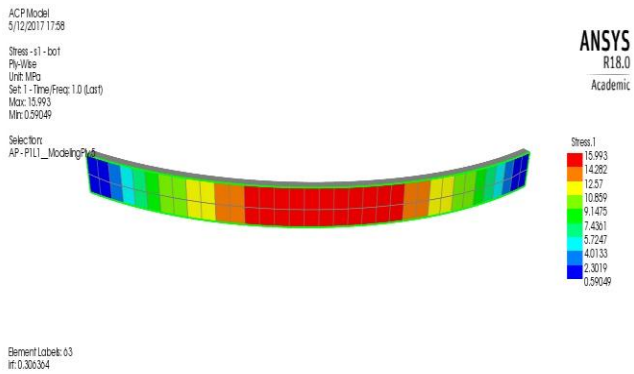

Fig -16: Stress Distribution in layer 5 of Leaf Spring

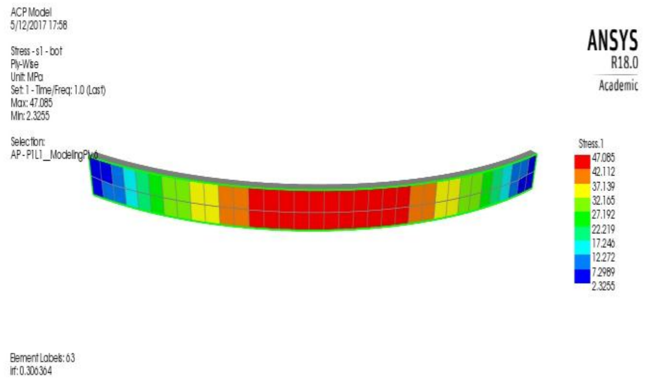

Fig -17: Stress Distribution in layer 6 of Leaf Spring

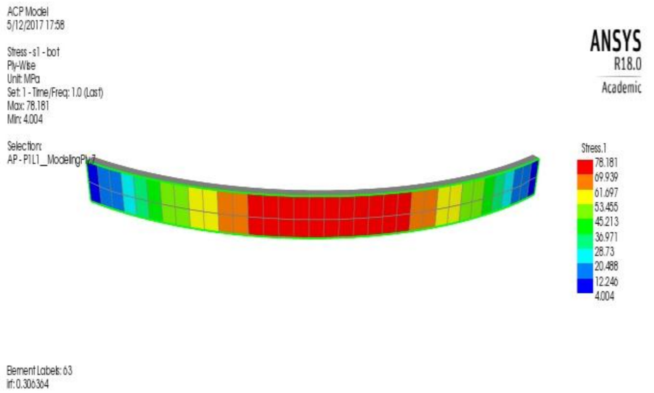

Fig -18: Stress Distribution in layer 7 of Leaf Spring

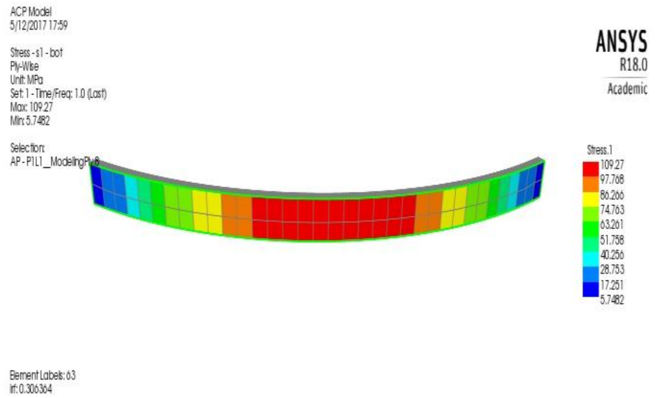

Fig -19: Stress Distribution in layer 8 of Leaf Spring

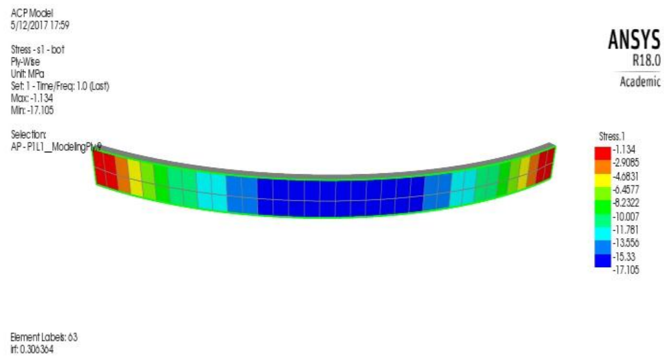

Fig -20: Stress Distribution in layer 9 of Leaf Spring

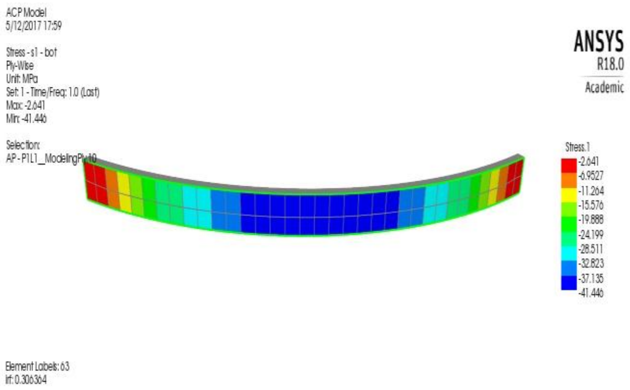

Fig -21: Stress Distribution in layer 10 of Leaf Spring

From finite element analysis, it can be observed that for a load of 6550 N the deformation of the leaf spring is 56.65 mm and equivalent stress is 294.34 N/mm^2.

The static stiffness of FRP leaf spring is given as,

k = Load F / Deformation δ

= 6550N/ 56.651 mm

k = 115.62 N/mm.

The static stiffness k of FRP leaf spring is 115.62 N/mm.

6. MODAL ANALYSIS OF LEAF SPRING

For automotive components normal modal analysis plays major role in design approval. To avoid resonance, leaf spring has to be designed for better comfort in such a way that its natural frequency does not coincide with the excitation frequency due to road roughness. Maximum excitation frequency due to road roughness is usually given as 12 Hz. [4] Figure 22 shows algorithm used for modal analysis of FRP leaf spring.

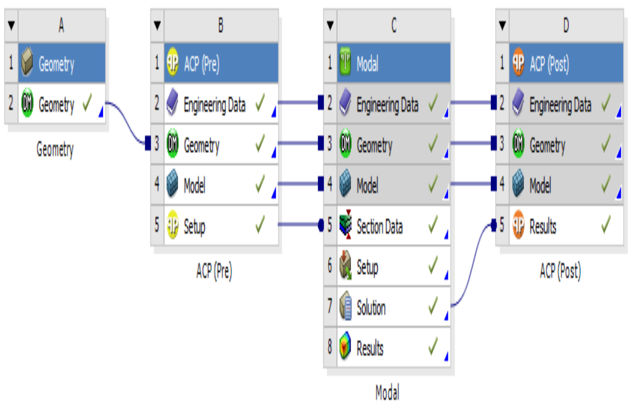

Fig -22: Algorithm used for Modal Analysis of FRP Leaf Spring

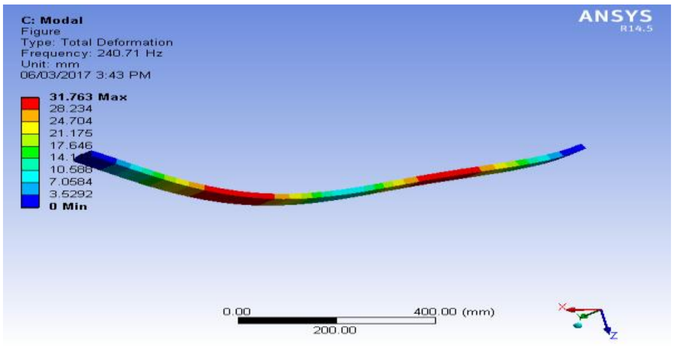

Fig -23: First Mode Shape of FRP Leaf Spring

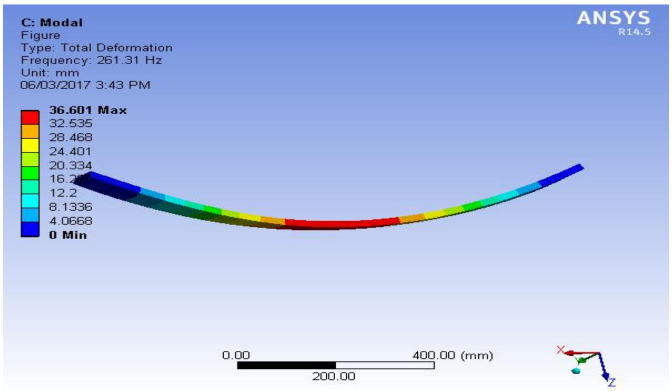

Fig -24: Second Mode Shape of FRP Leaf Spring

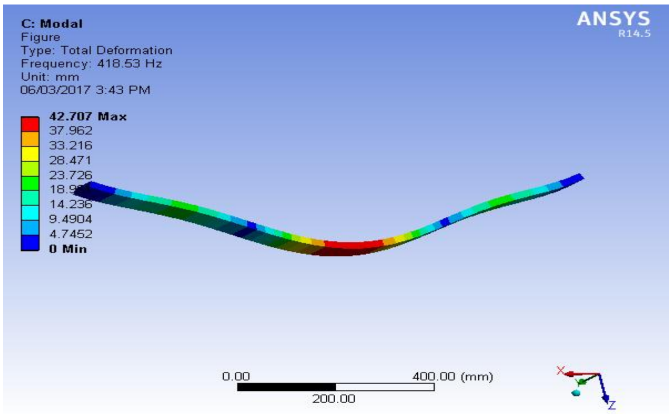

Fig -25: Third Mode Shape of FRP Leaf Spring

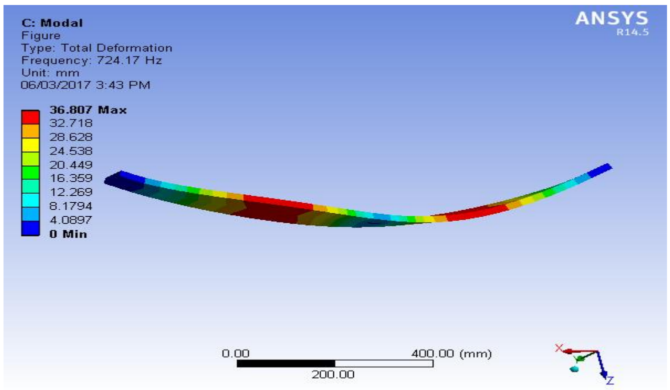

Fig -26: Fourth Mode Shape of FRP Leaf Spring

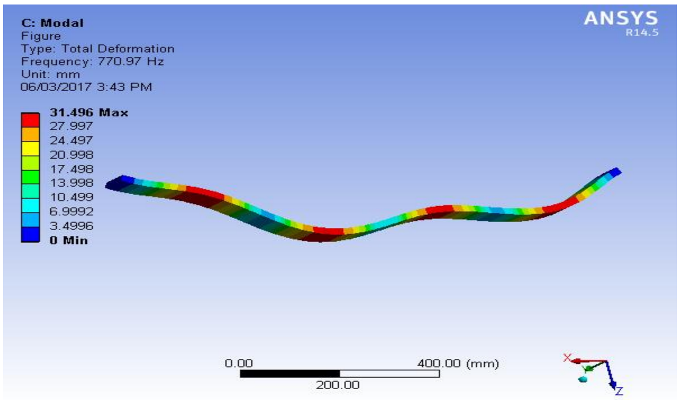

Fig -27: Fifth Mode Shape of FRP Leaf Spring

The first natural frequency of steel leaf spring is 240.71 Hz which much greater than the road excitation frequency of 12 Hz. [4] Hence resonance condition can be avoided in working condition of FRP leaf spring

7. DISCUSSION ON RESULTS

Modeling and finite element analysis of Hybrid FRP leaf spring has been carried out. Maximum equivalent stress induced in FRP leaf spring is 294.2 N/mm². Deformation of FRP leaf spring by using finite element analysis is found as 56.63 mm. Static stiffness of FRP leaf spring is obtained as 115.66 N/mm. first natural frequency of FRP leaf spring is obtained as 240.71 Hz which is much greater than the road excitation frequency of 12 Hz. [4] Hence resonance condition can be avoided in working condition of FRP leaf spring.

8. CONCLUSIONS

Modeling and finite element analysis of Hybrid FRP leaf spring has been carried out successfully.

Under dynamic loading, leaf spring using carbon fiber material will be suitable for vehicle suspension system.

Using FRP leaf spring with carbon fiber material, the resonance condition can be avoided since its first natural frequency is much higher than the road excitation frequency.

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