Modeling and Analysis of Mono Composite Leaf Spring under the Dynamic load condition using FEA for LCV

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Abstract: ***Leaf springs are widely used as automotive suspension to absorb shock loads. Suspension system in an automobile determines the riding comfort of passengers and the amount of damage to the vehicle. The main function of leaf spring assembly as suspension element is not only to support vertical load, but also to isolate road-induced vibrations. Another part has to be concentrated, is the automobile industry has shown increased interest in the replacement of steel spring with composite leaf spring due to strength factor and stiffness. Since the composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel. It is possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness. Therefore, analysis of the composite material becomes equally important to study the behavior of Composite Leaf Spring. The objective of the project is to replace the multi-leaf steel spring by mono composite leaf spring for the same load carrying capacity and stiffness by compare stresses and frequencies. Mono-composite leaf spring is designed for the same design specification except thickness so as to obtain the same stiffness for the same load carrying capacity and boundary conditions. Three different composite materials have been considered. They are e-glass/epoxy, graphite/epoxy and carbon/epoxy. Modeling is done by using CATIA V5 R19 and analysis is carried out by using ANSYS 15.0 software.***

Keywords: Leaf Spring, Composite materials, ANSYS V 15, CATIA V5 R19.

1. Introduction

Ever increasing needs of high performance together with increased life and light weight leads to consistent development of nearly each part of automobile. In Automobile Industry present day's Composite materials are used in place of metal parts. The performance characteristics of automobile are not only depend on shape and geometry but also stiffness is an important factor. Weight reduction of material used in automobile is mainly focused by automobile manufacturer for conserving natural resources and economizes energy. Better manufacturing processes. Design optimization and better material will leads to Weight reduction.

It is noted that absorb and release of store energy is done by springs which are the suspension elements. Hence, the strain energy of the material used becomes a major factor in designing the springs. The relationship between the specific strain energy and stress can be

$$U= \sigma 2 / \rho E$$

Where σ is the strength, ρ the density and E the Young's modulus of the spring material. It can be clearly noted that material having greater specific strain energy capacity will have lower modulus and lower density.

The leaf spring plays a vital role in automobile application which is one of the important components to provide a good suspension to absorb shocks. It carries lateral loads, brake and driving torque in addition to shock absorbing. The leaf spring have more advantage over helical spring since 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.

10% to 20% of the unsprang weight allocated by suspension leaf spring which is the major item for weight reduction in any automobile because steel is used as the major manufacturing element. The Riding qualities of automobile can be improved by achieving weight reduction. The weight of the leaf spring can be reduced without any reduction on load carrying capacity and stiffness by the introduction of composite materials like fiber reinforced plastics (FRP). Because, the fiber reinforced plastics have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel used, mono leaf FRP springs are replaced with multi-leaf steel springs without any change in load carrying capacity.

2. Literature Survey

Mahmood M.Shokrieh and Davood Rezaei [1] have studied the existing model of steel multi leaf spring dimensions and different loads acting on a spring. Suggest the composite materials like Glass fibre reinforced plastics for leaf spring manufacturing. Calculate the stain energies for the both steel and composite materials. And also given the different joints to attach the composite leaf springs to the vehicle body.

M.M. Patunkar and D.R. Dolas [2], M. Venkatesan and D. Helmen Devaraj [3] has made modelling and analysis of composite leaf spring under the static load condition. They take the E-Glass/Epoxy material as composite material and modeling has to be done for both steel and mono E-Glass/Epoxy materials and also these can be analyzed for varies loads in ANSYS V10. They concluded that reduction in weight by 84% for same level of performance using composite material in static load condition only.

Dadasaheb Gaikwad and Sameer Wagh [4] has given the brief information about different composite materials used like fibers and their compositions and also resins with their compositions. Manufacturing processes suitable for composite leaf springs.

Sorathiya Mehul and Dhaval B. Shah [5] studied the Analysis of Composite leaf spring using FEA The determination of the point of failure during an accident sequence of a rear leaf spring in a sport utility vehicle is presented in terms of fracture surface analysis and residual-strength estimates.

Thimmegowda RANGASWAMY, Sabapathy VIJAYARANGAN [6] has done experiment on the design optimization of composite drive shafts for power transmission applications. The one-piece composite drive shaft is designed to replace conventional steel drive shaft of an automobile using E-glass / epoxy and high modulus (HM) carbon/epoxy composites. A formulation and solution technique using genetic algorithms (GAs) for design optimization of composite drive shafts has been done. The purpose of using GA is to minimize the weight of shaft that is subjected to the constraints such as torque transmission, torsional buckling capacities and fundamental lateral natural frequency. The weight savings of the E-glass / epoxy and high modulus carbon/epoxy shaft were 48.36 % and 86.90 % of the steel shaft respectively.

Parkhe Ravindra and Sanjay belkar [7] has done the performance analysis of carbon fibre wih Epoxy resin based composite leaf spring. They take the carbon/Epoxy leaf spring properties and also EN47 Steel leaf spring properties. Manually calculate the bending stresses and also compare those results in ANSYS software and finally concluded that Epoxy resin based composite leaf spring have more tensile strength compared with carbon/Epoxy material.

Anandkumar A. Satpute and S.S. Chavan [8] has briefly given the manufacturing procedure of composite leaf spring and also experimentally take the results from UTM also compare the results with steel leaf spring and finally given the advantages of composite leaf springs over steel leaf springs. They choose hand lay-up technique which is an open type moulding process.

3. Modeling of Leaf Spring Model using CATIA Software

3.1 Modeling of Steel Leaf spring

In the present work, multi-leaf steel spring and mono-composite leaf spring are modeled. For modeling the steel spring, the dimensions of a conventional leaf spring of a light weight commercial vehicle are chosen. Since the leaf spring is symmetrical about the neutral axis only half of the leaf spring is modeled by considering it as a cantilever beam. Load is applied at the base of the leaf spring in the middle in the upward direction.

3.2 Specifications for Steel Leaf Spring

MODEL: CDR 650MD 2WD
SUSPENSION: REAR LEAF
SPAN LENGTH: 1120 mm
WIDTH: 50 mm
THICKNESS: 6 mm
OUTER EYE DIA.: 50 mm
DIA.OF CENTRE BOLT: 8 mm
CAMBER: 180 mm
TOTAL NO. OF LEAVES: 10
NO. OF FULL LENGTH LEAVES: 2
NO. OF GRADUATED LEAVES: 8
VEHICLE WEIGHT: 1910 Kg

3.3 Geometric Properties of leaf spring

Camber = 180 mm
Span = 1120 mm
Thickness = 6 mm
Width = 50 mm
Number of full length leaves nF = 2
Number of graduated leaves nG = 8
Total Number of leaves n = 10

Table 1: Design Parameters of Steel leaf spring

Leaf number	*Full leaf Length (mm)*	*Half leaf Length (mm)*	*Radius of Curvature (mm)*	*Half rotational Angle (Deg)*
1	1153.33	576.66	961.11	34.37
2	1153.33	576.66	967.11	34.37
3	1047.97	523.98	973.11	30.84
4	942.64	471.32	979.11	27.57
5	837.31	418.65	985.11	24.34
6	731.98	365.99	991.11	21.15
7	626.65	313.32	997.11	18.00
8	521.32	260.66	1003.11	14.88
9	415.99	207.99	1009.11	11.80
10	310.66	155.33	1015.11	8.76

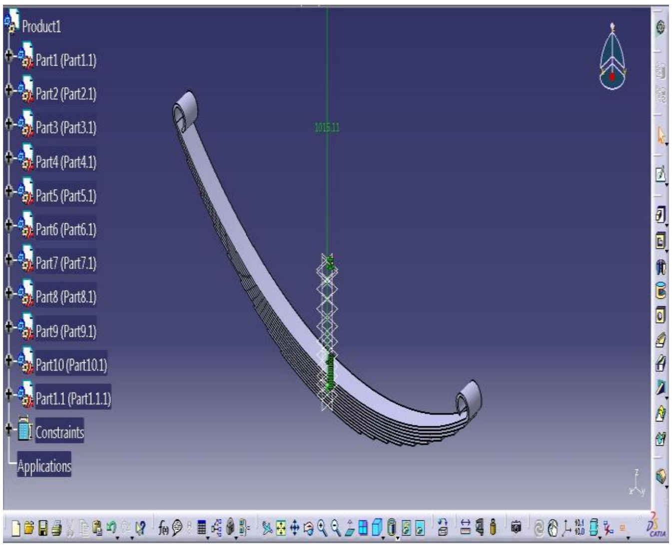

Figure 1: Solid Model of Steel Leaf Spring

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3.4 Specifications for Mono Composite Leaf Spring

Table 2: Geometric Properties of Mono Composite Leaf Spring

Material	Half Length (mm)	Width (mm)	Thickness (mm)	Radius of curvature (mm)	Half rotational Angle (Deg)
Carbon/epoxy	576.66	50	15.25	961.11	34.37
Graphite/epoxy	576.66	50	12.88	961.11	34.37
E-Glass/epoxy	576.66	50	24.45	961.11	34.37

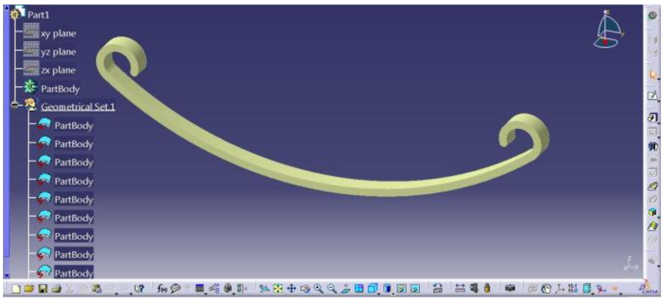

Figure 2: Solid Model of E-Glass/Epoxy Mono Composite Leaf Spring

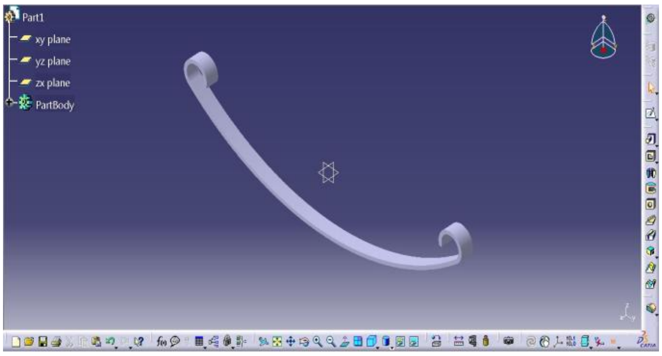

Figure 3: Solid Model of Graphite/Epoxy Mono Composite Leaf Spring

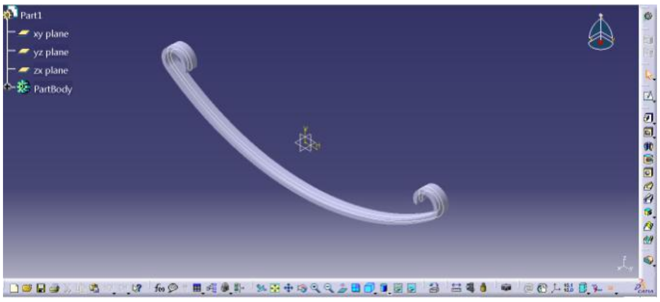

Figure 4: Solid Model of Carbon/Epoxy Composite Leaf Spring

4. Analysis of Leaf Spring

In the present work, for both multi-leaf steel spring and mono-composite leaf spring models the Static as well as modal analysis are carried out by using ANSYS V15 for the same loading conditions and boundary conditions.

4.1 Static Analysis of Leaf Spring

After prepared the model of the leaf spring by specifications it has to be subjected to analysis in ANSYS Workbench.

4.1.1Static Analysis of Multi leaf Steel Spring

Static Analysis involves apply meshing, giving boundary conditions and loads and obtain stress and strain values from the results obtained by the software.

Material Properties:
Material selected is Manganese Silicon Steel (Steel 55Si2Mn90)
Young's Modulus E = 2.1E5 N/mm2
Density = 7.86E-6 kg/mm3
Poisson's ratio = 0.3
Tensile stress = 1962 N/mm2
Yield stress = 1470 N/mm2

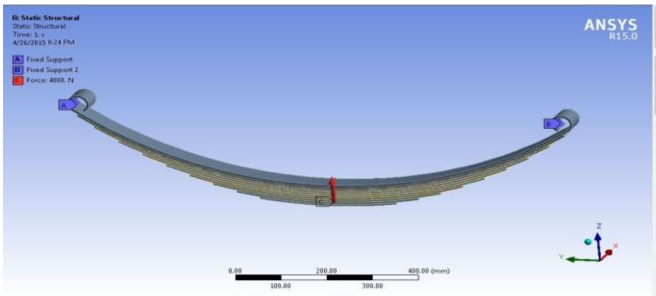

Figure 5: Steel Leaf Spring with Boundary Conditions

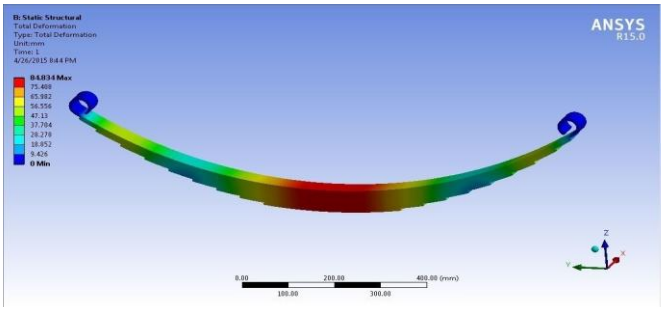

Figure 6: Deformed and Undeformed Plot of Steel Leaf Spring

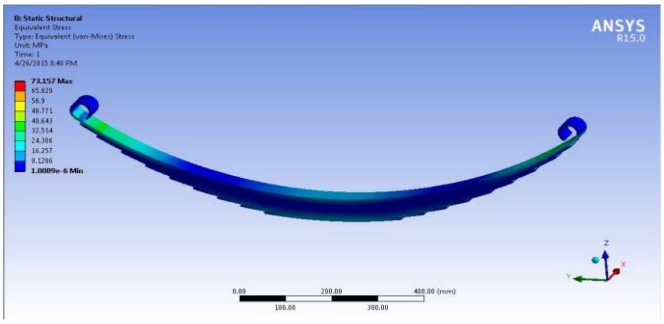

Figure 7: Vonmises-Stress Plot of Steel Leaf Spring

FE analysis for stress and deformation are carried out. The load of 4000N is applied at the base of leaf spring in the middle and the eyes of leaf spring are fixed in three directions i.e. along X, Y and Z axis. We can obtain the stresses and displacement by performing this analysis. From the results it is found that the maximum stress is 73.157Mpa and displacement is 84.834mm which are below the allowable limits.

4.1.2Static Analysis of Composite Steel Spring

Three different composite materials have been selected .They are E-Glass / Epoxy, Graphite / Epoxy and Carbon/ Epoxy composite materials. Analysis is done by using ANSYS Workbench.

(a) Static Analysis of E-Glass / Epoxy Leaf Spring

Material properties:

Youngs Modulus = 43E+3 MPa
Poisson's Ratio = 0.27
Density = 2000kg/m3
Yield strength = 2000MPa

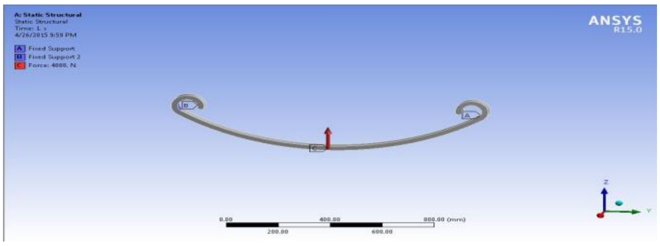

Fig.8 E-Glass/Epoxy Leaf Spring with Boundary Conditions

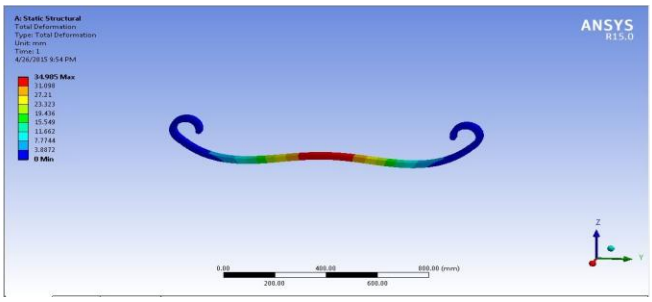

Figure 9: Total deformation of E-Glass/Epoxy Leaf Spring

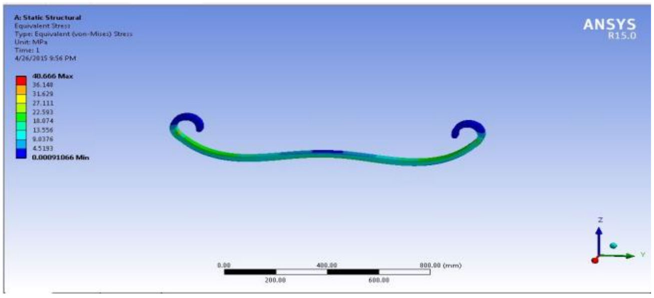

Figure 10: Von-Mises Stress Plot of E-Glass/Epoxy Leaf Spring

(b)Static analysis of Graphite / Epoxy Leaf spring

Material Properties:

Young's Modulus = 294E+3 MPa
Poisson's Ratio = 0.23
Density = 1590kg/m3
Yield Strength = 2067Mpa

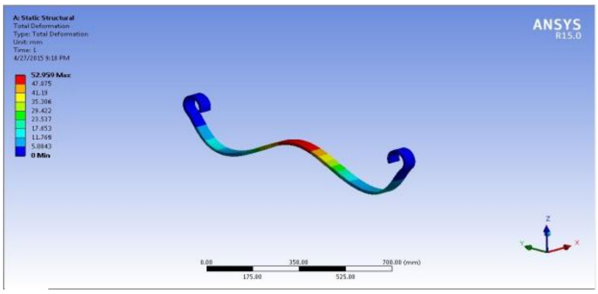

Figure 11: Total deformation of Graphite/Epoxy Leaf Spring

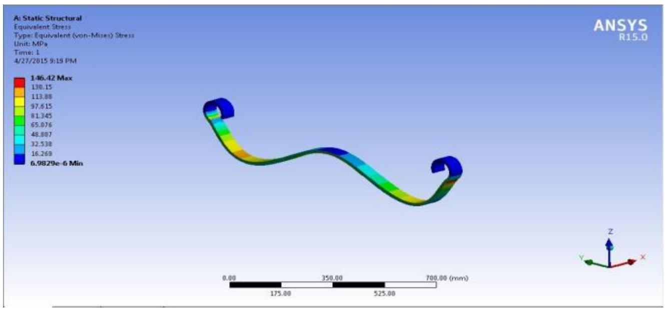

Figure 12: Von-Mises Stress Plot of Graphite/Epoxy Leaf Spring

(c)Static analysis of Carbon / Epoxy Leaf spring

Material Properties:

Young's Modulus = 177E+3 MPa
Poisson's Ratio = 0.27
Density = 1600kg/m3
Yield strength = 1900MPa

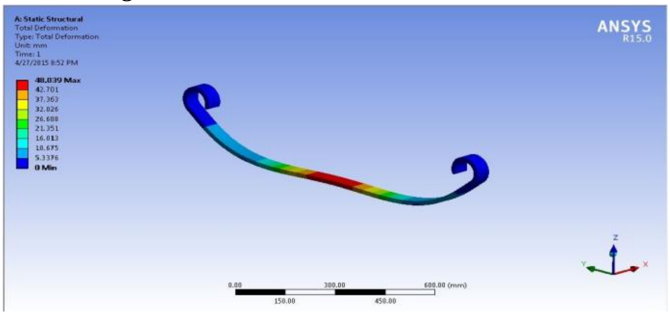

Figure 13: Total deformation of Carbon/Epoxy Leaf Spring

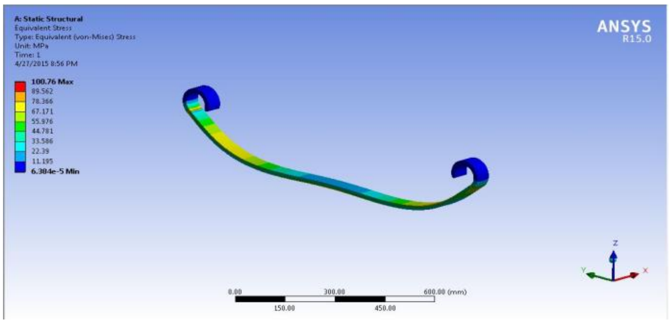

Figure 14: Von-Mises Stress Plot of Carbon/Epoxy Leaf Spring

Under the same loading and boundary conditions i.e. the load of 4000N applied at the middle of the leaf Spring and the eyes are fixed in the X,Y and Z directions the results obtained from the three composite leaf springs for E-Glass/Epoxy the maximum stress for is 40.66Mpa and displacement is 34.985mm and for Graphite / Epoxy the maximum stress for is 146.42Mpa and displacement is 52.959mm and for Carbon / Epoxy the maximum stress for is 100.76Mpa and displacement is 48.03mm which are below the allowable limits.

4.2 Modal Analysis of Leaf Spring

Modal analysis is carried out to determine the natural frequencies and mode shapes of the leaf spring. Modal analysis need only boundary conditions, it is not associated with the loads applied, because natural frequencies are resulted from the free vibrations. The boundary conditions are same as in the case of static analysis.

4.2.1Modal Analysis of Multi leaf Steel Spring

Modal analysis is performed to determine the natural frequencies and mode shapes of the leaf spring. After the meshing operation, from solution options, new analysis is selected as modal in ANSYS Workbench. The subspace method is selected. In the next step select the no. of modes to extract and expand are taken as 4.

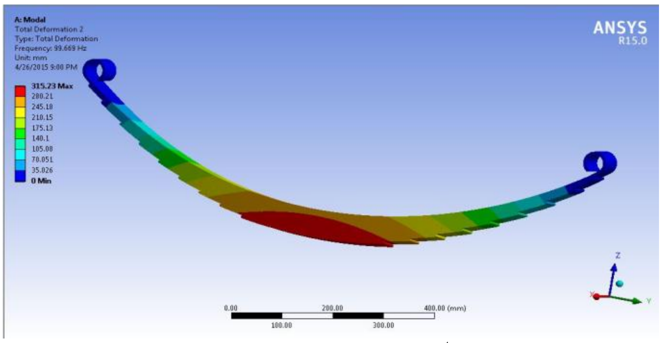

Figure 15: Total Deformation Plot for 1st Natural Frequency

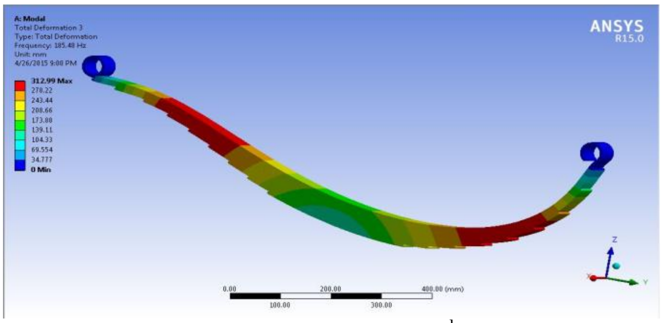

Figure 16: Total Deformation Plot for 2nd Natural Frequency

From the modal analysis results, the natural frequencies of the steel leaf spring are found to be 99.66Hz, 185.48Hz, 338.36Hz and 381.17Hz.

4.2.2Modal Analysis of Composite Steel Spring

Modal analysis is performed to determine the natural frequencies and mode shapes of the composite leaf spring.

(a) Modal Analysis of E-Glass / Epoxy Leaf Spring

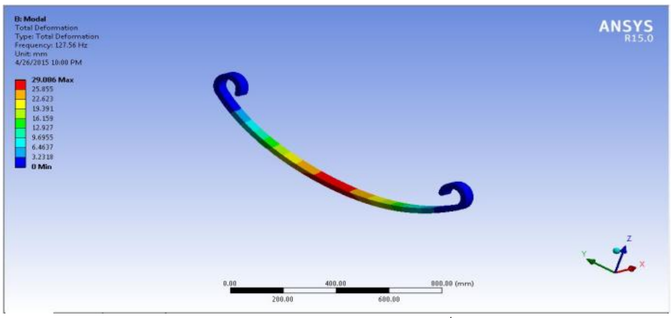

Figure 17: Total Deformation Plot for 1st Natural Frequency

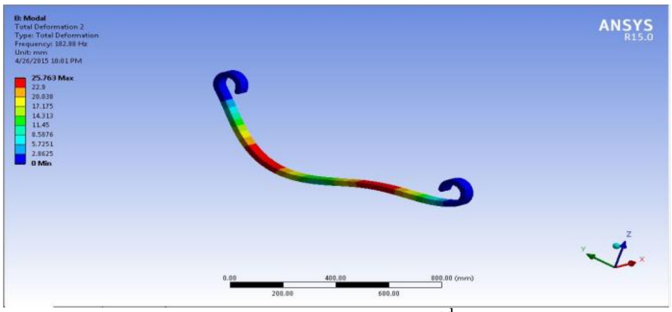

Figure 18: Total Deformation Plot for 2nd Natural Frequency

From the modal analysis results, the natural frequencies of the E-Glass / Epoxy leaf spring are found to be 127.56Hz, 182.88 Hz, 328.05 Hz and 360.46 Hz.

(b) Modal Analysis of Graphite / Epoxy Leaf Spring

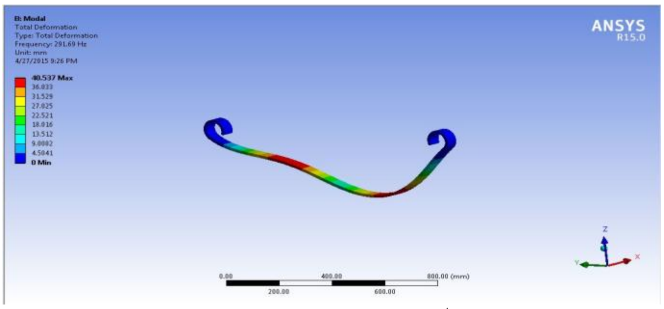

Figure 19: Total Deformation Plot for 1st Natural Frequency

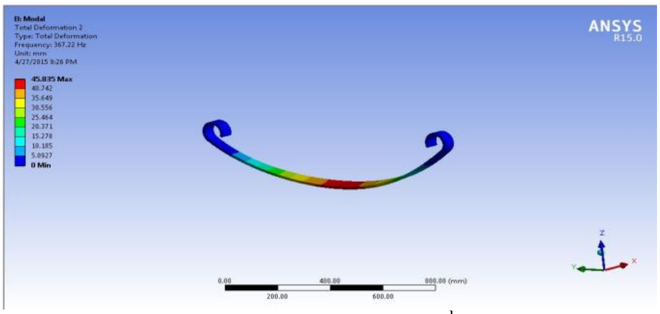

Figure 20: Total Deformation Plot for 2nd Natural Frequency

From the modal analysis results, the natural frequencies of the Graphite / Epoxy leaf spring are found to be 291.96Hz, 367.22 Hz, 542.25 Hz and 986.65 Hz.

(c) Modal Analysis of Carbon / Epoxy Leaf Spring

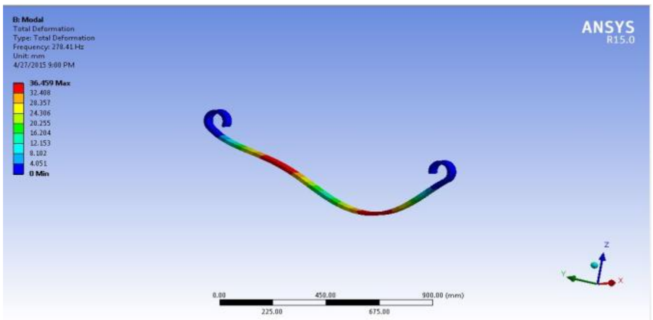

Figure 21: Total Deformation Plot for 1st Natural Frequency

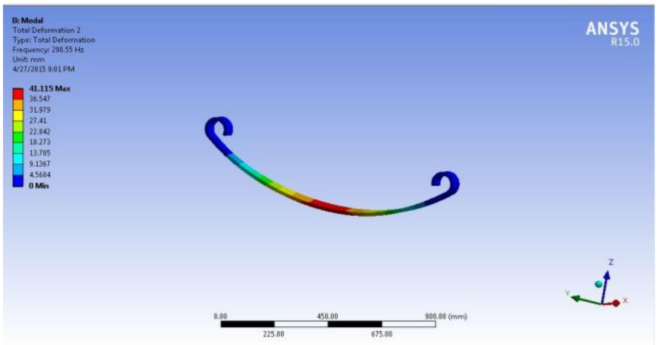

Figure 22: Total Deformation Plot for 2nd Natural Frequency

From the modal analysis results, the natural frequencies of the Carbon / Epoxy leaf spring are found to be 278.41Hz, 290.55 Hz, 514.11 Hz and 820.95 Hz.

5. Calculations

Calculation of load applied on the leaf spring
Vehicle weight = 1910 kg = 1910 x 9.81 = 18737.1N
Load on each leaf spring = 18737.1 / 4 = 4684.275N
Load acting at the eye end = 4684.275 / 2=2342 N
Factor of safety = 1.5
Load applied = 4000 N
Calculation of thickness of mono composite leaf springs using the formula
Δ = (4 FL 3) / Enbt3

Where
Δ = Deflection of steel leaf spring = 92.591mm (Obtained from FEA result)
F = Applied load = 4000N
L = Half length of the leaf spring = 566.66mm
n = Number of leaves = 1
b = width of the leaf spring = 50
E = Youngs Modulus = 43 x 103 MPa (E-Glass / Epoxy)
= 294 x 103 MPa (Graphite / Epoxy)
= 177 x 103 MPa (Carbon / Epoxy)
Thickness of E-Glass / epoxy leaf spring = 24.45 mm
Thickness of Graphite / epoxy leaf spring = 12.88 mm
Thickness of Carbon / epoxy leaf spring = 15.25 mm
Calculation of bending stress in the leaf springs using the formula [9]
σ = 6FL / n bt2
n = 10 (For steel leaf spring)
= 1 (For mono composite leaf spring)
σ = 63.36MPa (Steel leaf spring)
= 48MPa (E-Glass/ Epoxy leaf spring)
= 123 MPa (Carbon / Epoxy leaf spring)
= 164MPa (Graphite/Epoxy leaf spring)

6. Results and Discussions

Table 3: Displacement and Stiffness Results

Material	Displacement (mm)	Stiffness (N/mm)
Steel	85	47
E Glass/Epoxy	35	114
Carbon /Epoxy	48	83
Graphite /Epoxy	53	75

Table 4: Theoretical and Ansys Results

Material	Theoretical Stress (MPa)	Von-Mises Stress(MPa)
Steel	75	73
E Glass/Epoxy	48	40
Carbon/Epoxy	123	100
Graphite/Epoxy	164	146

Table 5: Modal Analysis Results

Set	E Glass/Epoxy (Hz)	Carbon/ Epoxy(Hz)	Graphite/ Epoxy (Hz)
1	127.56	278.41	291.96
2	182.88	290.55	367.22
3	328.05	514.11	542.25
4	360.46	820.55	986.65

From the table 4, it is observed that the stress in E-Glass / Epoxy is less than the stress in steel as well as other composite leaf springs. So from both the stiffness point of view and based on stress, E-Glass / epoxy can be used for replacing the steel leaf spring with mono-composite leaf spring. Since the composite leaf spring is able to withstand the static load, it is concluded that there is no objection from strength point of view also, in the process of replacing the conventional leaf spring by composite leaf spring.

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