Published by :
http://www.ijert.org
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 05, May-2018

Design and Analysis of Leaf Spring using Composite Materials

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***Abstract* - In now a day the fuel efficiency and emission gas regulation of automobiles are two important issues. To fulfill this problem the automobile industries are trying to make new vehicle which can provide high efficiency with low cost. The best way to increase the fuel efficiency is to reduce the weight of the automobile. The weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The achievement of weight reduction with adequate improvement of mechanical properties has made composite a very good replacement material for conventional steel.**

The automobile vehicles have number of parts which can be able to replace by composite material, but due to the improvement of mechanical properties of composite material. It has more elastic strength and high strength to weight ratio has compared with those of steel material. So, out of many components one of the components of automobile, the leaf spring which use for carried out the whole weight of the vehicle is best option for replacement of steel material by composite material.

For reduce the weight of leaf spring the analysis was carried out on the model of Mahindra Pickup's leaf spring with same dimensional geometry . The material selected for leaf spring are AS4, T300, E-Glass 21*K43 Gevetex and Silenka E-Glass 1200tex composite material which is more economical with similar mechanical and geometrical properties to the steel leaf spring. The analysis was carried out on ANSYS 15.0 with same loading condition for deflection and bending stress of steel as well as AS4, T300, E-Glass 21*K43 Gevetex and Silenka E-Glass 1200tex composite materials.

A comparative study has been made between steel and composite leaf spring with respect to strength and weight. Composite leaf spring reduces the weight by 60% forE-glass 21xK43Gevetex, 74.23% for T300 and 74.82% for AS4 and 59.7% Silenka over steel leaf spring.

1. INTRODUCTION

In now a day the fuel efficiency and emission gas regulation of automobiles are two important issues. To fulfill this problem the automobile industries are trying to make new vehicle which can provide high efficiency with low cost. The best way to increase the fuel efficiency is to reduce the weight of the automobile. The weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The achievement of weight reduction with adequate improvement of mechanical properties has made composite a very good replacement material for conventional steel. In automobile, one of its components which can be easily replaced is leaf spring. A leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. The suspension of leaf spring is the area which needs to focus to improve the suspensions of the vehicle for comfort ride. The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for 10 to 20% of unsprung weight.

It is well known that springs are designed to absorb shocks. So the strain energy of the material becomes a major factor in designing the springs. The introduction of composite material will make it possible to reduce the weight of the leaf spring without reduction in load carrying capacity and stiffness. Since the composite material have high strength to weight ratio and have more elastic strain energy storage capacity as compared with steel.

The relationship of specific strain energy can be expressed as

$$U = \frac{1}{2} * \frac{\sigma^2}{\rho * E}$$

It can be easily observed that material having lower density and modulus will have a greater specific strain energy capacity. Thus composite material offer high strength and light weight. In this work, leaf spring of automobile vehicle is Mahindra "Model-Commander 650di" car is considered for further investigation. The suspension quality can be improved by minimizing the vertical vibrations, impacts and bumps due to road irregularities which create the comfortable ride.

The automobile sector is introducing a number of cars which are newly designed, modified with replacing new parts with advanced and composite material for better Comfort ride, low weight and having better mechanical properties.

India is a country with more than one billion people, require vehicle to move anywhere around the country for their personal and transportation purpose. We have personally seen and observed that vehicle having no smoothed suspension or comfort ride create the tiredness to the people and more especially to drivers of car who is the life of passenger. Also, now days so many passenger cars available in the state of Gujarat which can especially used in local transport around 200 to 300 km, a day with overloading of passengers which increase the total weight of the vehicle and also increase the fuel consumption which leads to noise and breakage problem in the suspension of leaf springs and create the pollution in the environment. So for further analysis to increase fuel efficiency and to reduce the pollution the commercial vehicle Mahindra "Model-Commander 650di" is considered.

TYPES OF SPRING

1) Helical springs

2) Conical and volute springs

3) Torsion springs

4) Disc or Belleville springs

5) Special purpose springs

6) Laminated or leaf springs

2. DIMENSIONS OF LEAF SPRING

Conventional design methods of leaf springs are largely based on the application of empirical and semi-empirical rules along with the use of available information in the existing literature. The functions of springs are absorbing energy and release this energy according to the desired functions to be performed. So leaf springs design depends on load carrying capacity and deflection. Hence the Mahindra "Model-Commander 650di" is consider for design of leaf spring.

MATERIAL OF LEAF SPRING

- E-glass 21xK43 Gevetex
- AS4
- Silenka E-glass 200tex
- T300

BASIC DATA OF MAHINDRA PICKUP LEAF SPRING

1. Total length of the spring (Eye to Eye) = 1120 mm
2. No. of full length leaves (nf) = 1
3. Thickness of leaf (t) = 5 mm
4. Width of the leaf spring (b) = 50 mm
5. Total load = 500 N
6. BHN = 420 – 430 HB with hardened and tempered

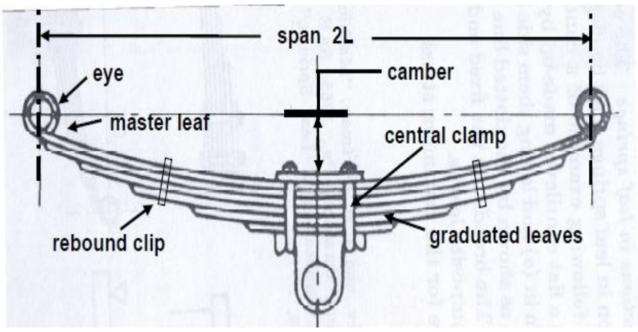

Figure 1 Terminology of Leaf Spring

3. MODELING AND ANALYSIS OF STEEL LEAF SPRING

INTRODUCTION OF ANSYS WORKBENCH

Based on the dimensions obtained from the conventional design of leaf spring, the model of the leaf spring was created with the help of the ANSYS Workbench 15.0 software.

ANSYS Workbench is modeling software for modeling various mechanical designs for performing related design and manufacturing operations. The system uses a 3D solid modeling system as the core, and applies the feature base parametric modeling method.

In short ANSYS Workbench is a feature based parametric solid modeling system with many extended design and manufacturing applications. Some of the features of ANSYS Workbench are as below:

- Ease of use
- Parametric & feature based modeling
- Robustness

MODELING OF LEAF SPRING

Modeling of leaf spring is performed in ANSYS Workbench. There are different procedures available for modeling of leaf spring. Here we utilize divisional method of generation of parabolic leaf spring.

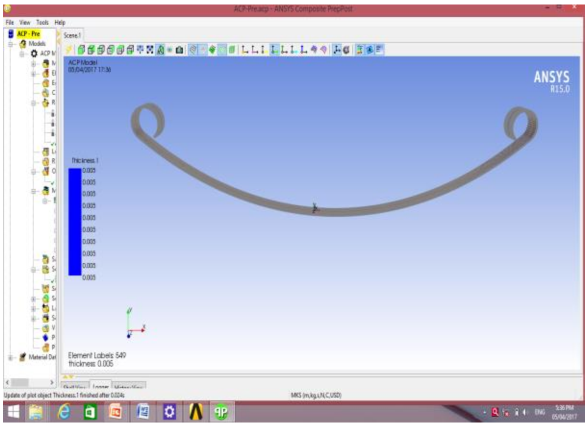

Figure 2 Sketch of Master Leaf

INTRODUCTION OF ANSYS

ANSYS is a finite element analysis (FEA) software package. It uses a preprocessor software engine to create geometry. Then it uses a solution routine to apply loads to the meshed geometry. Finally it outputs desired results in post-processing. FEA is used throughout almost all engineering design including mechanical systems and civil engineering structures.

In most structural analysis applications it is necessary to compute displacements and stresses at various points of interest. The finite element method is a very valuable tool for studying the behavior of structures. In the finite element method, the finite element model is created by dividing the structure in to a number of finite elements. Each element is interconnected by nodes. The selection of elements for modeling the structure depends upon the behavior and geometry of the structure being analyzed. The modeling pattern, which is generally called mesh for the finite element method, is a very important part of the modeling process. The results obtained from the analysis depend upon the selection of the finite elements and the mesh size. Although the finite element model does not behave exactly like the actual structure, it is possible to obtain sufficiently accurate results for most practical applications. The goal of meshing in ANSYS Workbench is to provide robust, easy to use meshing tools that will simplify the mesh generation process. These tools have the benefit of being highly

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 05, May-2018

automated along with having a moderate to high degree of user control.

❖ ADVANTAGES OF FEA
- Visualization increases
- Design cycle time reduces
- No. of prototypes reduces
- Testing reduces
- Optimum design

The process of performing ANSYS can be broken down into three main steps.

PRE-PROCESSING

This step is most important in analysis of leaf spring. Any modeling software can be used for modeling of geometry and can be shifted to other simulation software for analysis purpose. After mesh generation (grid generation) is the process of subdividing a region to be modeled into a set of small elements. Meshing is the method to define and breaking up the model into small elements. In general a finite element model is defined by a mesh network, which is made up of the geometric arrangement of elements and nodes. Nodes represent points at which features such as displacements are calculated. Elements are bounded by set of nodes, and define localized mass and stiffness properties of the model. Elements are also defined by the number of mesh, which allowed reference to be made to corresponding deflections, stresses at specific model location. The common type of mesh element used in ANSYS solver is hexahedral, tetrahedral and brick.

SOLVER

During preprocessing user has to work hard while solution step is the turn of computer to do the job. User has to just click on solve icon. Internally software carries out matrix formations, inversion, multiplication & solution for unknown. E.g. displacement & then find strain & stress for static analysis.

POST-PROCESSING

The final step in ANSYS is Post-processing, during which the ANSYS results are analyzed. However, the real value of ANSYS simulation is frequently found in its ability to provide accurate predictions of integrated quantities such as find displacement and stresses. Post processing is viewing results, verifications, conclusions & thinking about what steps could be taken to improve the design.

ASSUMPTIONS
- Software to be used for ANSYS 15.0
- Model simplification for FEA.
- Meshing size is limited to computer compatibilities.
- Static analysis is considered.

PROPERTIES OF STEEL MATERIAL

Table 1 Properties of Steel Material

PROPERTIES	VALUES
Density	7850 Kgm^{-3}
Young's Modulus	2E+11 Pa
Poison's Ratio	0.3 Pa
Bulk Modulus	1.6667E+11 Pa
Shear Modulus	7.6923E+10 Pa
Tensile Yield Strength	2.5E+08 Pa
Compressive Yield Strength	2.5E+08 Pa
Tensile Ultimate Strength	4.6E+08 Pa

STATIC ANALYSIS OF STEEL LEAF SPRING
1) After creating solid model of steel leaf spring in ANSYS Workbench 15.0. Save that model in STEP format.
2) Import above 3D model in ANSYS Workbench static structural module for static analysis.

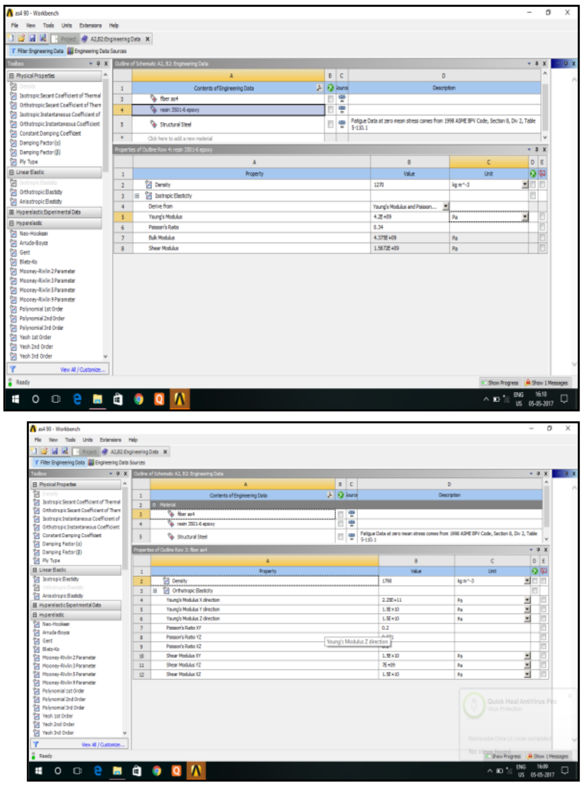

Figure 3 Define Materials in ANSYS Workbench

ANALYSIS OF COMPOSITE LEAF SPRING

As mentioned earlier, the ability to absorb and store more amount of energy ensures the comfortable option of a suspension system. However, the problem of heavy weight of spring is still persistent. This can be remedied by introducing composite material, in a place of steel in the conventional leaf spring. Research has indicated that the results of E-glass/epoxy, carbon epoxy were found with good characteristics for storing strain energy. So, a virtual model of leaf spring was created in ANSYS workbench and then material is assigned to the model. These results can be used for comparison with the steel leaf spring.

International Journal of Engineering Research & Technology (IJERT)
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❖ ASSUMPTIONS:

- Software to be used for ANSYS 15.0
- Model simplification for FEA
- Meshing size is limited to computer capabilities.
- Static analysis is considered.
- Material used for leaf spring analysis is isotropic.

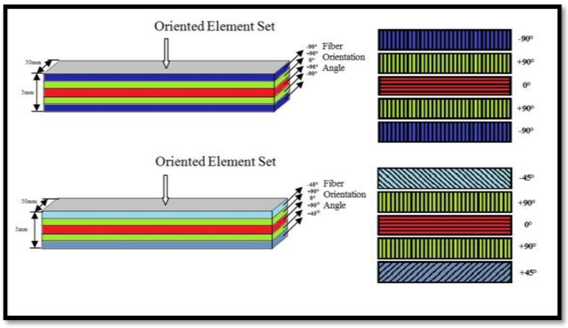

Figure 4 Fiber Orientation

❖ PROPERTIES OF COMPOSITE MATERIAL:

Sr. no.	Properties	AS4	T300	E-glass 21xK43 Gevetex	Silenka E-glass 1200tex
1.	Ex	2.25E+11	1.38E+11	5.34E+10	4.56E+10
2.	Ey	1.5E+10	1.1E+10	1.77E+10	1.62E+10
3.	Ez	1.5E+10	1.1E+10	1.77E+10	1.62E+10
4.	PRxy	0.2	0.28	0.278	0.287
5.	PRyz	0.071	0.4	0.4	0.4
6.	PRzx	0.2	0.28	0.278	0.287
7.	Gxy	1.5E+10	5.5E+9	5.83E+9	5.83+9
8.	Gyz	7E+9	1.96E+9	6.32E+9	6032E+9
9.	Gzx	1.5E+10	5.5E+9	5.83E+9	5.83+9
10.	ρ	1790	1770	2550	2570

Table 2 Properties of Composite Material

STATIC ANALYSIS OF COMPOSITE LEAF SPRING

1. Create the model of steel leaf spring in ANSYS Workbench 15.0 static structural module for static analysis.
2. Create leaf spring material E-glass/epoxy.
   - Provide material properties as per table 5.1 in the ANSYS Workbench

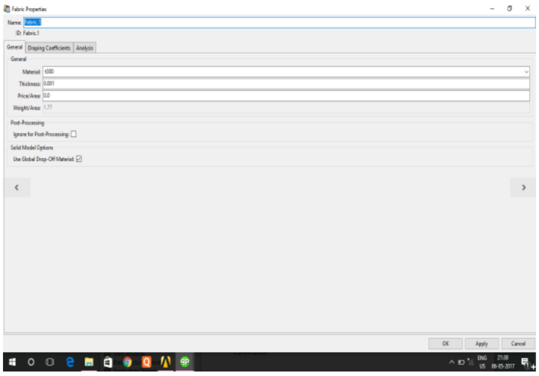

Figure 5 Define Materials in ANSYS Workbench

3. Assign material to mono leaf spring

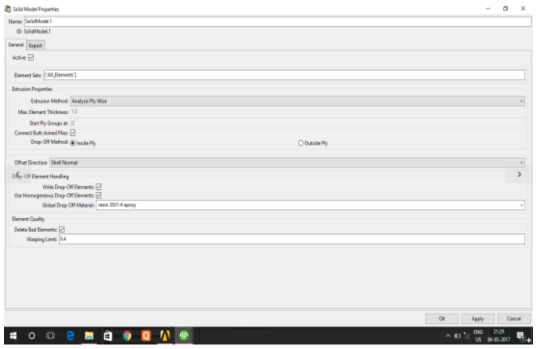

Figure 6 Apply Materials at Mono Leaf Spring

4. Create meshing of Leaf spring

This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of the structure. The mesh has been generated automatically. As shown in figure 5.3number of elements used are and number of nodes used are

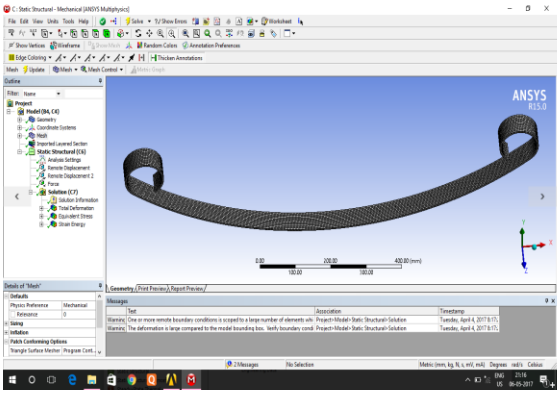

Figure 7 Meshed Model of Leaf Spring

5. Apply boundary conditions and loading condition

Figure 8 Nodes of Leaf Spring

- Define displacement constrain.

End	X-component	Y-component	Z-component	X-rotation	Y-rotation	Z-rotation
1.	0	0	0	0	0	0
2.	Free	0	0	0	0	0

Table 3 Boundary Condition When Vehicle is New

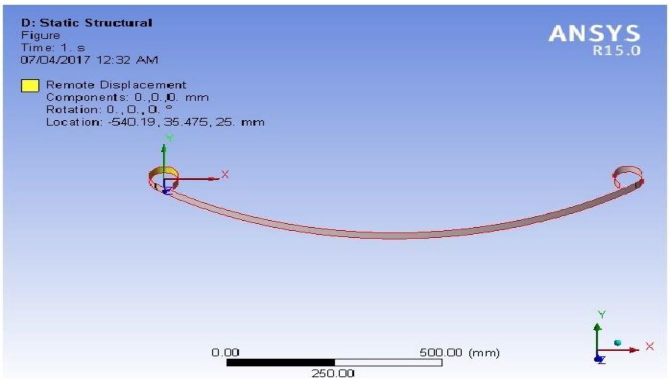

Figure 9 Remote Displacements at First End

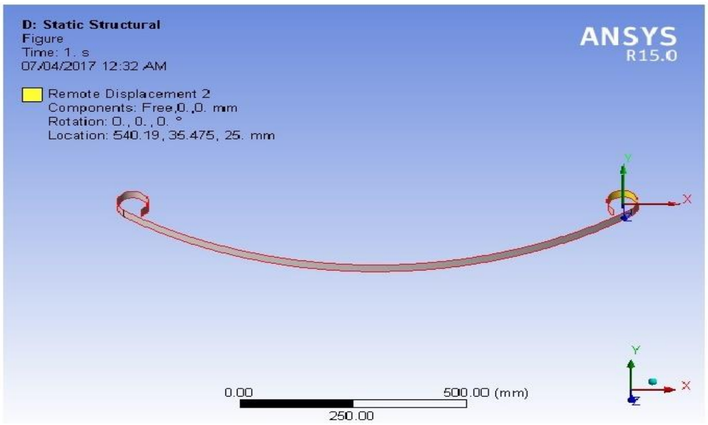

Figure 10 Remote Displacement Condition at another End

End	X-component	Y-component	Z-component	X-rotation	Y-rotation	Z-rotation
1.	0	0	0	0	0	Free
2.	Free	0	0	0	0	Free

Table 4 Boundary Conditions When Vehicle Become Old

6. Run analysis.
7. Get results.

RESULT ANALYSIS OF COMPOSITE LEAF SPRING

- Von misses stress contour

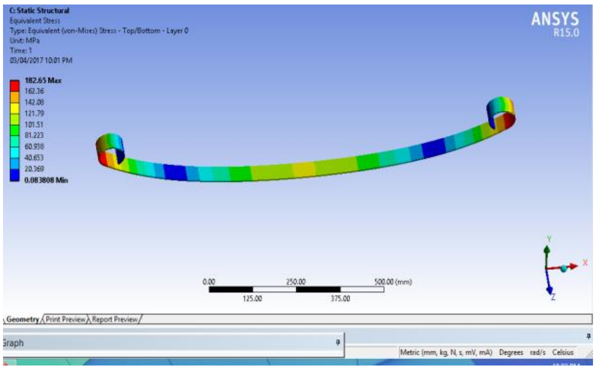

Figure 11 Von Misses Stress Contour of AS4 at Orientation of 90/90/0/90/-90

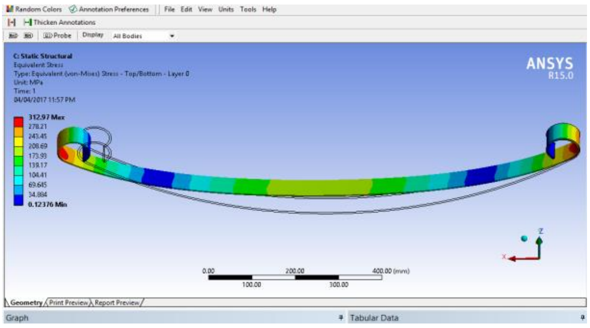

Figure 12 Von Misses Stress Contour of AS4 at Orientation of -45/90/0/90/45

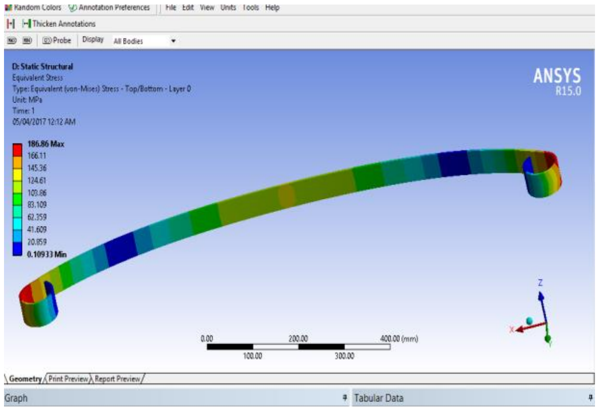

Figure 13 Von Misses Stress Contour of T300 of Orientation 90/90/0/90/-90

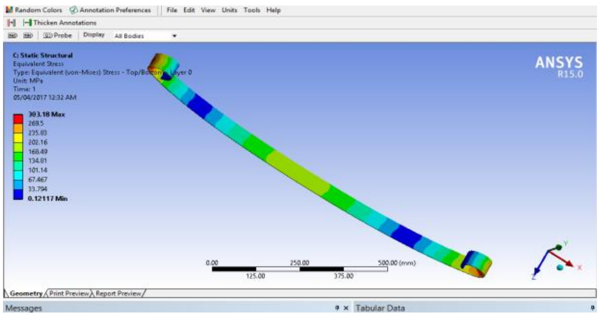

Figure 14 Von Misses Contour of T300 of Orientation -45/90/0/90/45

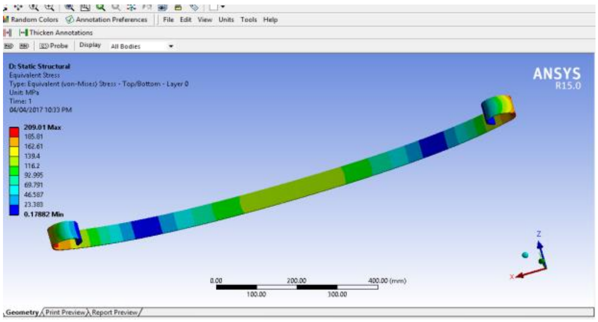

Figure 15 Von Misses Stress Contour of E-Glass21x43 Gevetex of Orientation 90/90/0/90/-90

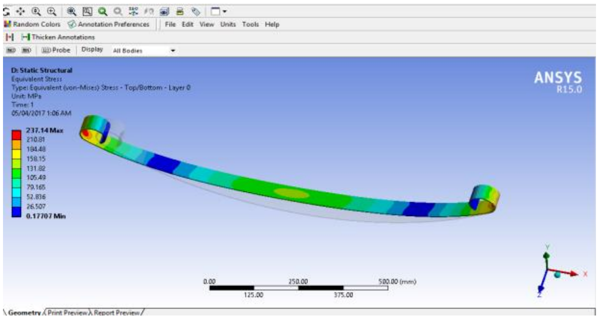

Figure 16 Von Misses Stress Contour of E-Glass21x43 Gevetex at Orientation-45/90/0/90/45

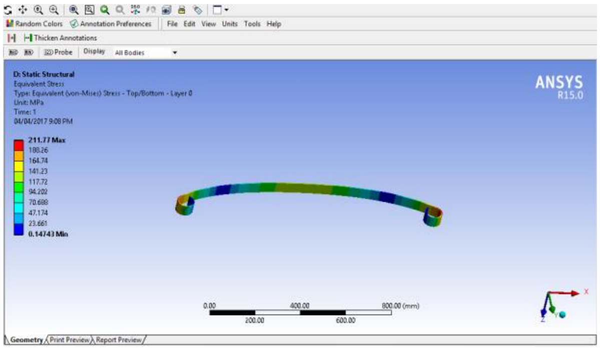

Figure 17 Von Misses Stress Contour of Silenka E-Glass 1200tex at Orientation of 90/90/0/90/-90

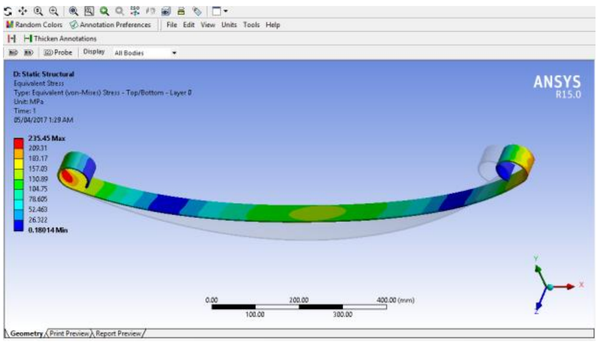

Figure 18 Von Misses Stress Contour of Silenka E-Glass 1200tex at Orientation -45/90/0/90/45

- Maximum deflection contour

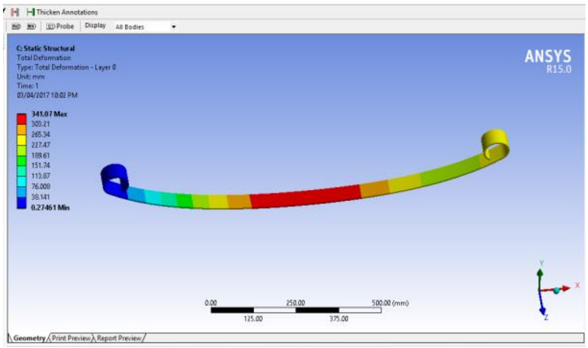

Figure 19 Maximum Deflection Contour of AS4 at Orientation 90/90/0/90/-90

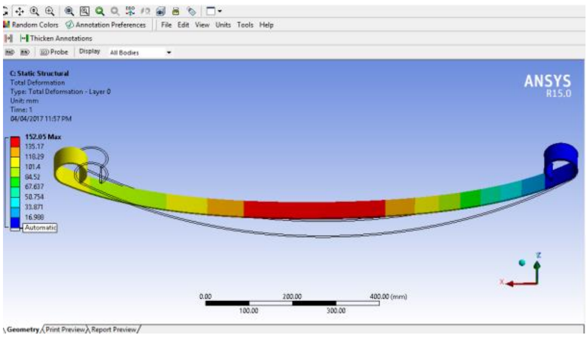

Figure 20 aximum Deflection Contour of AS4 at Orientation of -45/90/0/90/45

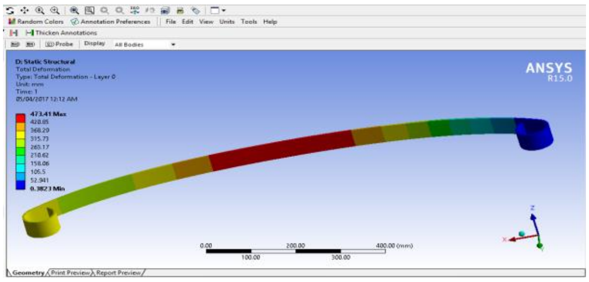

Figure 21 Maximum Deflection Contour of T300 at Orientation 90/90/0/90/-90

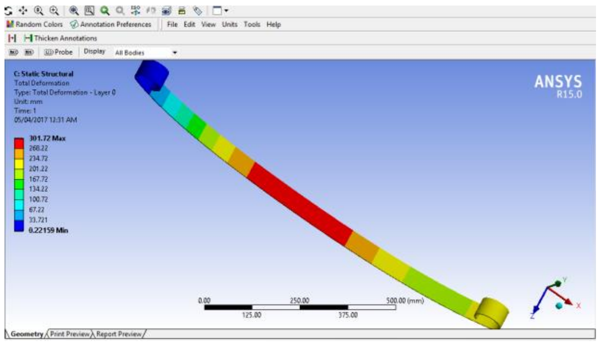

Figure 22 Maximum Deflection Contour of T300 at Orientation -45/90/0/90/45

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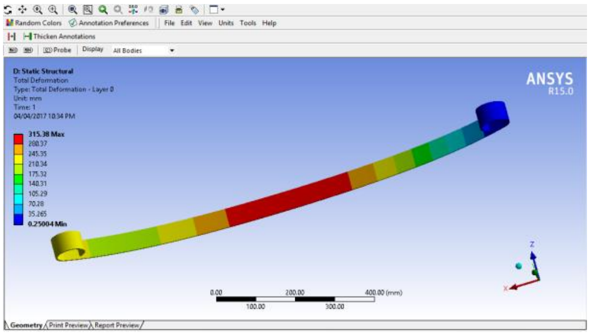

Figure 23 Maximum Deflection Contour of E-Glass21x43Gevetex Orientation 90/90/0/90/-90

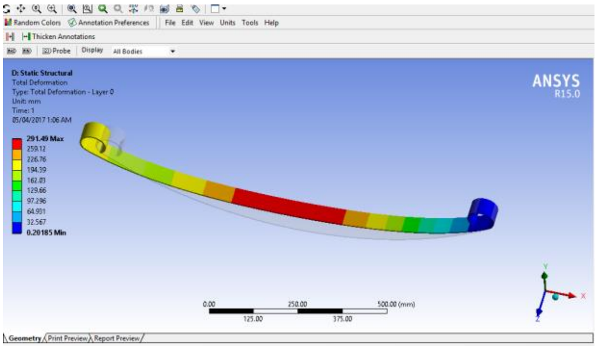

Figure 24 Maximum Deflection of E-Glass21x43Gevetex at Orientation-45/90/0/90/45

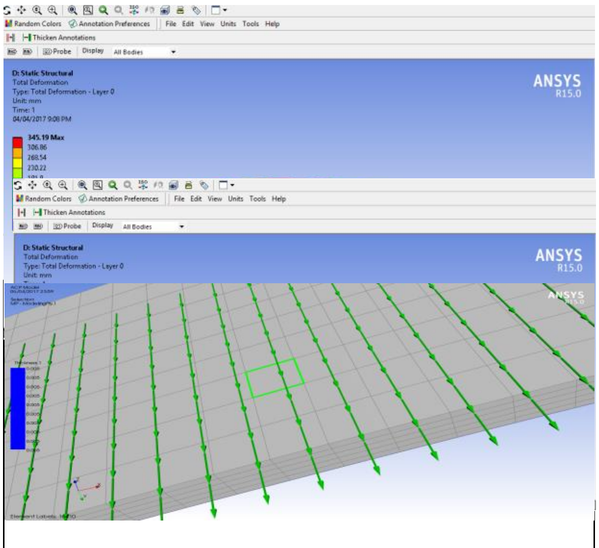

Figure 27 Orientation of Fiber along -90º

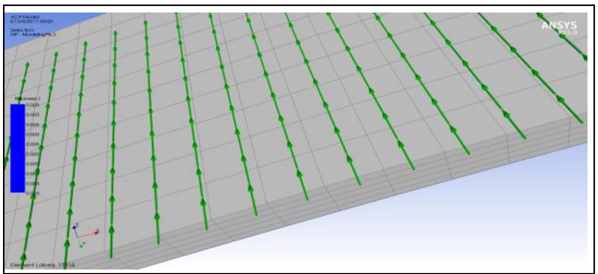

Figure 28 Orientation of Fiber along 90º

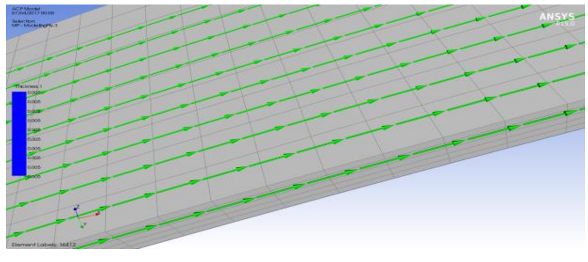

Figure 29 Orientation of Fiber along 0º

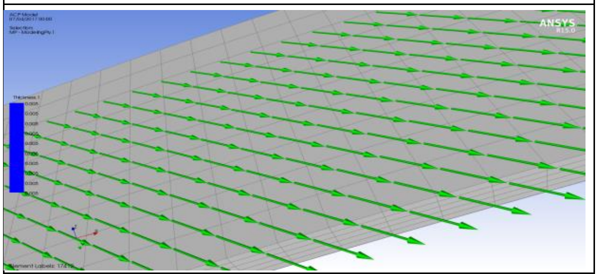

Figure 30 Orientation of Fiber along -45º

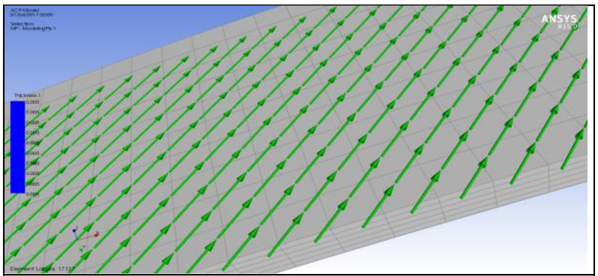

Figure 31 Orientation of Fiber along 45º

COMPARISON OF STEEL AND COMPOSITE LEAF SPRING

Material	Orientation	Stress (MPa)	Deflection (mm)	Mass (kg)
AS4	-90/90/0/ 90 /-90	182.65	341.07	0.68
	-45/90/0 /90/45	307.58	174.27	
T300	-90/90/0 /90/-90	186.86	473.41	0.75
	-45/90/0 /90/45	299.01	345.42	
E-glass 21xk43 gevetex	-90/90/0 /90/-90	209.01	365.38	1.08
	-45/90/0 /90/45	227.97	334.63	
Silenka E-glass 1200tex	-90/90/0 /90/-90	205.38	386.18	1.09
	-45/90/0 /90/45	224.28	347.30	
Structural steel	Linear isotropic	219.36	19.03	2.70

Here, from comparison of steel leaf spring with composite leaf spring as shown in table 5.4. It can be seen that maximum deflection 473.41mm on T300 at orientation -90/90/0/90/-90 and corresponding deflection in AS4, E-glass21xk43 Gevetex and Silenka E-glass 1200tex are 341.07mm, 315.38mm and 386.18 mm at -90/90/0/90/-90 orientation respectively. Also, the von misses stresses in the steel leaf spring 219.16 MPa, while in AS4, E-glass 21xk43 Gevetex and Silenka E-glass 1200tex are 183.65, 209.01 and 205.38 MPa respectively. A comparative study has been made between steel and composite leaf spring with respect to strength and weight. Composite leaf spring reduces the weight byv74.82% for AS4, 72.23% for T300, 60% for E-glass 21xk43 Gevetex and 59.7% for Silenka E-glass 1200tex leaf spring.

CONCLUSION

The design and static structural analysis of steel leaf spring and composite leaf spring has been carried out. Comparison has been made between composite leaf spring with steel leaf spring having same design and same load carrying capacity. The stress and displacements have been calculated using analytically as well as using ANSYS for steel leaf spring and composite leaf spring. From the static analysis results it is found that there is a maximum displacement of 19.02 mm in the steel leaf spring and the corresponding displacements in AS4, T300, E-glass 21xk43 Gevetex and Silenka E-glass 1200tex are 341.07mm, 473.41mm, 365.38mm and 386.18mm respectively at orientation -90/90/0/90/-90. From the static analysis results, it also seen that the von-mises stress in the steel leaf spring is 219.36 MPa and in AS4, T300, E-glass 21xk43 Gevetex and Silenka E-glass 1200tex in are 182.65 MPa, 186.86 MPa and 227.97 MPa respectively at orientation -90/90/0/90/-90. All the four composite leaf springs have lower stresses than that of existing steel leaf spring.

A comparative study has been made between steel and composite leaf spring with respect to strength and weight. Composite leaf spring reduces the weight by 74.82% for AS4, 72.23% for T300, 60% for E-glass 21xk43 Gevetex and 59.7% for Silenka E-glass 1200tex over steel leaf spring. The size optimization has been carried out for further mass reduction of composite leaf spring.

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