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Comparative Analysis of Multi Leaf Spring and Composite Leaf Spring using Finite Element Method Under Static Loading Condition

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Abstract **- The work is carried out on the front end multi leaf spring of a commercial vehicle. In this analysis the conventional steel leaf spring is tested for static loading condition and results are compared with a virtual model of composite multi leaf spring. The material used for conventional steel leaf spring is 65Si7 (BIS) and for composite leaf spring E-Glass/ Epoxy. The CAD model of the multi leaf spring is prepared in Solid works 16 and analyzed using ANSYS 16. The FE analysis of the leaf spring has been performed by discretization of the model in infinite nodes and elements and refining them under defined boundary condition. Bending stress and deflection are the target results. A comparison of both i.e. experimental and FEA results have been done to conclude.**

Keywords- **CAE, E-Glass/Epoxy, FEA, Leaf Spring, 65Si7.**

I. INTRODUCTION

Increasing competition and innovations in automobile sector tends to modify the existing products or replacing old products by new and advanced material products. A suspension system of vehicle is also an area where these innovations are carried out regularly. More efforts are taken in order to increase the comfort of user. Appropriate balance of comfort riding qualities and economy in manufacturing of leaf spring becomes an obvious necessity. To improve the suspension system many modification have taken place over the time. Inventions of multi leaf spring, use of composite materials for these springs are some of these latest modifications in suspension systems.

In this analysis the conventional steel leaf spring is tested for static load condition and results are compared with a virtual model of composite material leaf spring. CAE tools are widely used in the automotive industries. In fact, their use has enabled the automakers to reduce product development cost and time while improving the safety, comfort, and durability of the vehicles they produce. The predictive capability of CAE tools has progressed to the point where much of the design verification is now done using computer simulation rather than physical prototype testing. CAE dependability is based upon all proper assumptions as inputs and must identify critical inputs. Even though there have been many advances in CAE, and it is widely used in the engineering field, physical testing is still used as a final confirmation for subsystems due to the fact that CAE cannot predict all variables in complex assemblies, therefore the validation of CAE results is important. Leaf spring is modeled in Solidworks 16.0 CAD software and it is imported and simulated in ANSYS 16.0 for better understanding. Results of Composite Leaf Spring are compared on the basis of analysis reports produced by ANSYS software. The material used for conventional steel leaf spring is 65Si7 (BIS) and for composite leaf spring E-Glass/ Epoxy material is used.

II. LITERATURE SURVEY

Many industrial visits, past recorded data shows that steel leaf springs are manufactured by EN45, EN45A, , EN47, 50Cr4V2, 55SiCr7, 50CrMoCV4, 60Si7 and 65Si7 etc. These materials are widely used for production of the parabolic/ Multi leaf springs and conventional multi leaf springs. 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. Studies and researches were carried out on the applications of the composite materials in leaf spring. The main objective of this work is to perform finite element analysis of multi leaf spring and composite leaf spring. Experimental results have been taken on a full scale static load testing machine, in which leaf spring is held under an axial load at center till maximum deflection. These experimental results will be compared with conventional and composite FEA results for validation.

III. DESIGN PARAMETERS OF THE MULTI LEAF SPRING USED IN THIS WORK ARE

Total span length (eye to eye): 1450mm Number of full length leaves: 02, Length of full length leaves (L-1 and L-2): 1450 mm each, Width of all leaves: 70mm, Thickness of all leaves: 12mm, Number of graduated length leaves: 07, Length of graduated length leaves; (L-3, L-4, L-5, L-6, L-7, L-8 and L-9): 1320mm, 1140mm, 940mm, 800mm, 640mm, 464mm & 244mm respectively.

1. Material Properties for the conventional Leaf Spring: The table 1 is showing the different parameters of conventional Leaf Spring.

Table I: Conventional Leaf Spring

S N	Parameters	Values
1	Material selected- Steel	65Si7
2	Total Length of spring (Eye to Eye) (mm)	1450
3	No. of full length leave (Master Leaf)	02
4	Width of leaf spring (mm)	70
5	Thickness of leaf (mm)	12
6	Tensile Ultimate strength (MPa)	1272
7	Tensile Yield strength (MPa)	1158
8	Young□s Modulus E (MPa)	$2.1x 10^5$
9	Poisson□s Ratio	0.266
10	Hardness (BHN)	400-425
11	Stiffness (N/mm)	221.5
12	Density (kg mm^-3)	7.85e-006
13	No load camber angle (^{o})	159
14	Maximum Normal Static Load (N)	35000
15	Behavior	Isotropic

The ability to absorb and store more amount of energy ensures the comfortable operation of a suspension system. However, the problem of heavy weight of spring is still persistent. This can be remedied by introducing composite material, in place of steel in the conventional leaf spring. From several studies it is found that the E-glass/Epoxy is better material for replacing the conventional steel as per strength and cost factor. The E-glass fiber is a high quality glass, which is used as standard reinforcement fiber for all the present systems well complying with mechanical property requirements. The material select is E-Glass/Epoxy material.

Material Properties for the composite Leaf Spring: The table 2 is showing the different parameters of composite Leaf Spring.

Table II: E-Glass/Epoxy material

SN	Parameters	Values
1	Tensile modulus along X-direction (Ex), MPa	34000
2	Tensile modulus along Y-direction (Ey), MPa	6530
3	Tensile modulus along Z-direction (Ez), MPa	6530
4	Tensile strength of the material, MPa	900
5	Compressive strength of the material, MPa	450
6	Shear modulus along XY-direction (Gxy), MPa	2433
7	Shear modulus along YZ-direction (Gyz), MPa	1698
8	Shear modulus along ZX-direction (Gzx), MPa	2433
9	Poisson ratio along XY-direction (NUxy)	0.217
10	Poisson ratio along YZ-direction (NUyz)	0.366
11	Poisson ratio along ZX-direction (NUzx)	0.217
12	Mass density of the material (□), Kg/mm3	$2.6x 10^{-6}$
13	Flexural modulus of the material, MPa	40000
14	Flexural strength of the material, MPa	1200

2. Multi Leaf Spring Geometry and Boundary Conditions: The two dimensional drawing of the multi leaf spring is shown in the figure-1 below;

The multi leaf spring is modeled maximum deflection i.e. flat position reverse direction to attain its original shape i.e. semi elliptical. The static Loading condition of the multi leaf spring involves the fixation of one of the revolute joint and applying displacement support at the other end of leaf spring.

Loading conditions involves applying a load at the center of the main leaf. As per specifications the spring is drawn at flat condition, therefore the load is applied in downward direction to achieve initial no load condition. As no load assembly camber is 159°. The loading conditions are shown below in the figure;

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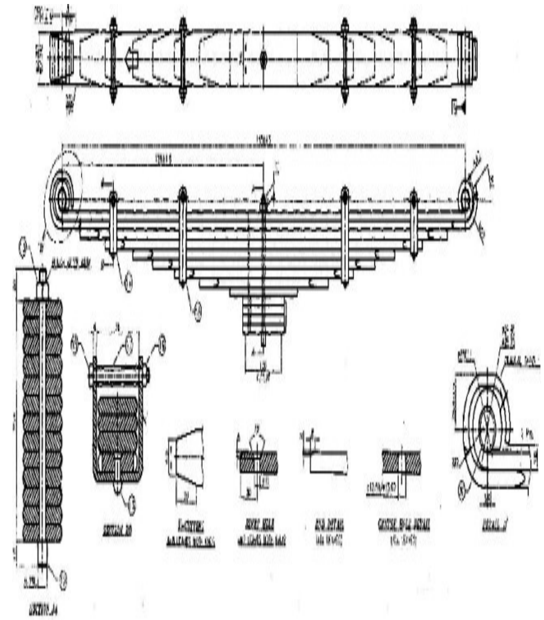

Fig .1. Drawing of Multi Leaf Spring.

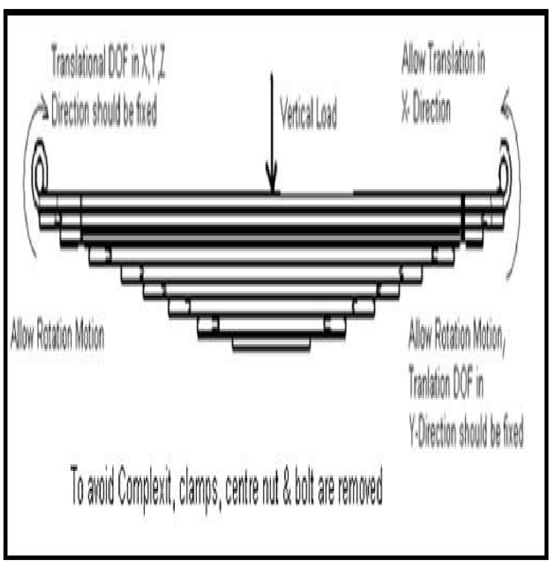

Fig.2. Experimental Boundary Conditions.

3. Modeling & Finite Element Analysis: Meshing is the process in which your geometry is spatially discredited into elements and nodes. This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of your structure. The default element size is determined based on a number of factors including the overall model size, the proximity of other topologies, body curvature, and the complexity of the feature. If necessary, the fineness of the mesh is adjusted up to four times (eight times for an assembly) to achieve a successful mesh. In this assembly SOLID92 element is used for discretization of Multi leaf Spring Modal.

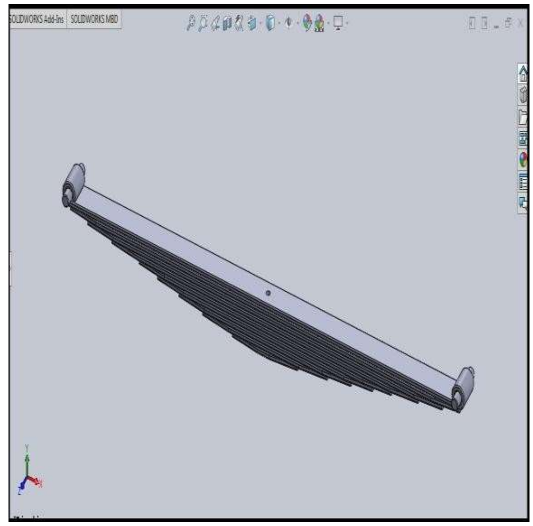

Fig .3. Assembly Design in Solidworks.

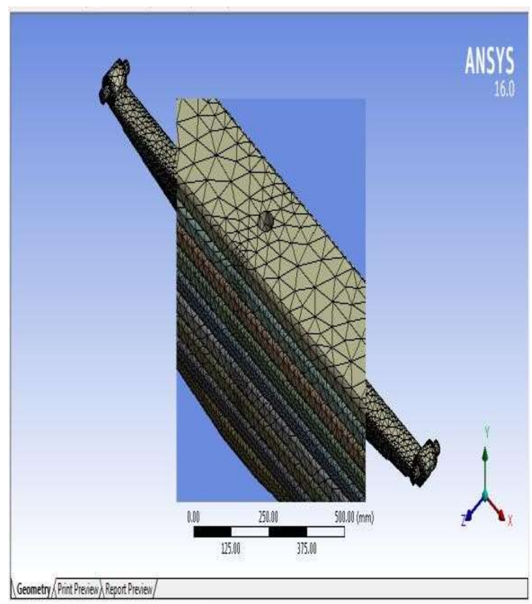

Fig.4. Meshing of Assembly.

4. Finite Element Analysis: A stress-deflection analysis is performed using finite element analysis (FEA). The complete procedure of analysis has been done using ANSYS-16. To conduct finite element analysis, the general process of FEA is divided into three main phases, preprocessor, solution, and postprocessor.

5. Preprocessor: The preprocessor is a program that processes the input data to produce the output that is used as input to the subsequent phase (solution). Following are the input data that needs to be given to the preprocessor:

(i) Type of analysis
(ii) Material properties
(iii) Geometric model
(iv) Meshed model
(v) Loading and boundary conditions.

IV. SOLUTION

Solution phase is completely automatic. The FEA software generates the element matrices, computes nodal values and derivatives, and stores the result data in files. These files are further used by the subsequent phase (postprocessor) to review and analyze the results through the graphic display and tabular listings.

V. POSTPROCESSOR

The output from the solution phase is in the numerical form and consists of nodal values of the field variable and its derivatives. For example, in structural analysis, the output is nodal displacement and stress in the elements. The postprocessor processes the result data and displays them in graphical form to check or analyze the result. The graphical output gives the detailed information about the required result data.

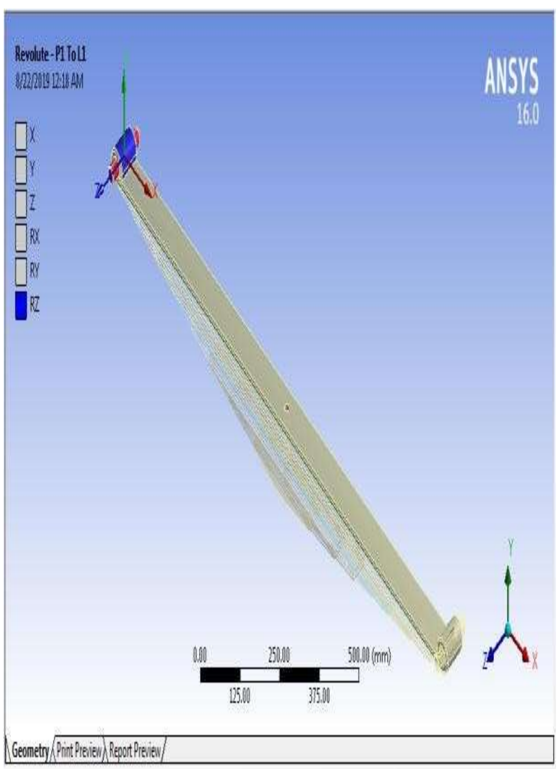

Fig .5. Eye end with pin.

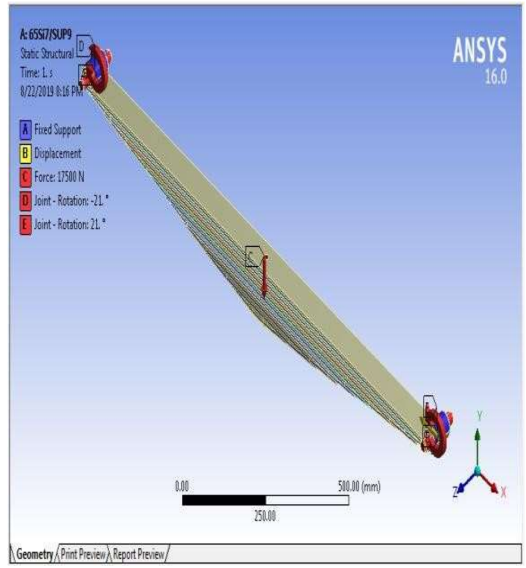

Fig .6. Boundary Conditions in ANSYS-16.

VI. RESULT AND DISCUSSIONS

As the finite element analysis of multi leaf spring is performed using Ansys 16 detailed above, in which all conditions are considered which were also considered for results taken by experimental testing. The multi leaf spring showing deflections under half & full rated loads are shown in fig 7 and fig 9, as well as in tabular form taken from Ansys 16.

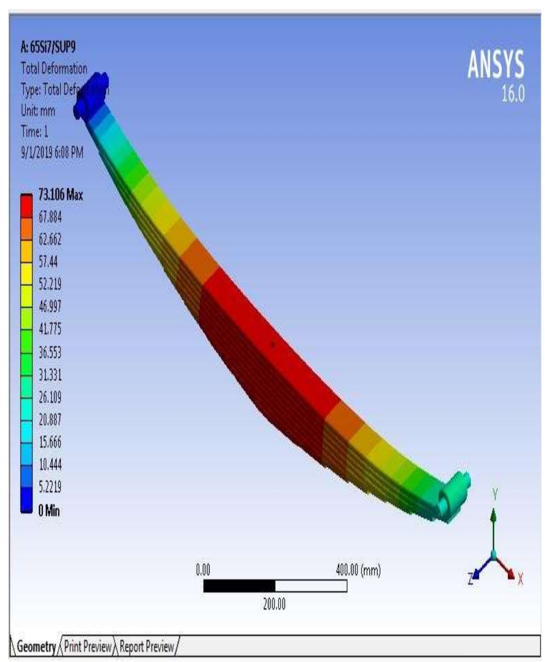

Fig.7. Deformation at 17500 N

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Table III: Multi Leaf Spring Result Comparison at 17500 N

SN	Para-meter	Theoretical Results	Exp. Results	Vari-tion
1.	Normal Static Load	17500 N	17500 N	Nil
2.	Deflection	71.60 mm	72.5 mm	1.26 %
3.	Spring Rate	244.4 N/mm	241.38 N/mm	1.23 %
4.	Bending Stress	514.92 MPa	561.50 MPa	9.05 %

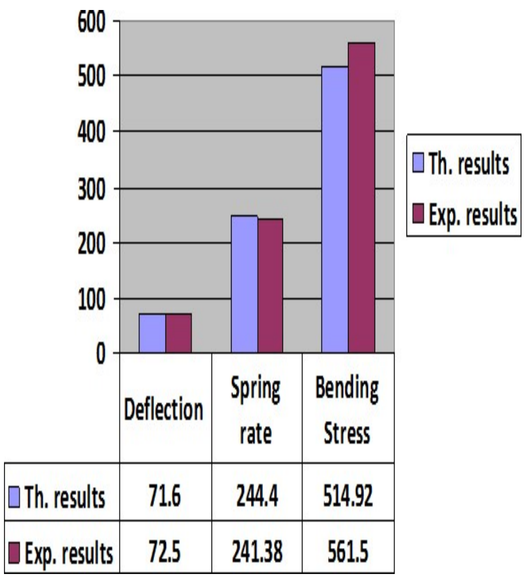

Fig .8. Deflection - spring rate - bending Stress of multi leaf Spring at 17500 N.

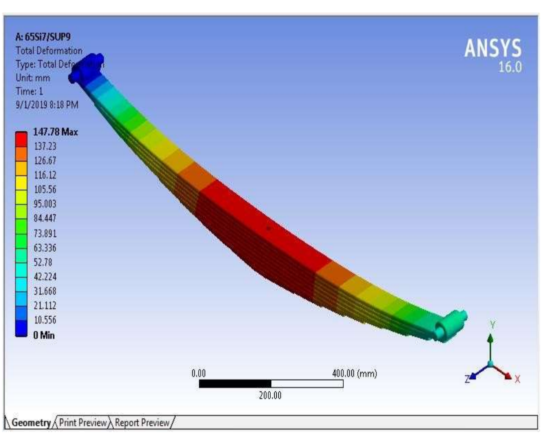

Fig .9. Deformation at 35000 N.

Table IV: Multi Leaf Spring Result Comparison at 35000 N

S N	Para-meter	Theoretical Results	Exp. Results	Vari-ation
1.	Normal Static Load	35000 N	35000 N	Nil
2.	Deflection	143.20 mm	145.5 mm	1.61 %
3.	Spring Rate	244.41 N/mm	240.54 N/mm	1.58 %
4.	Maximum Stress	1029.84 MPa	1148.5 MPa	11.52 %

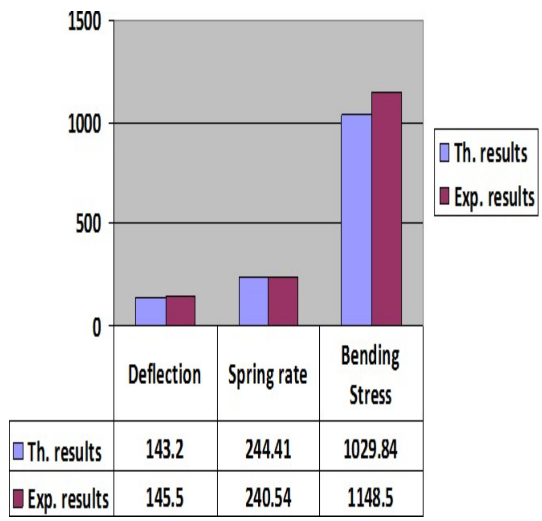

Fig. 10. Deflection - spring rate - bending Stress of multi leaf Spring at 35000 N.

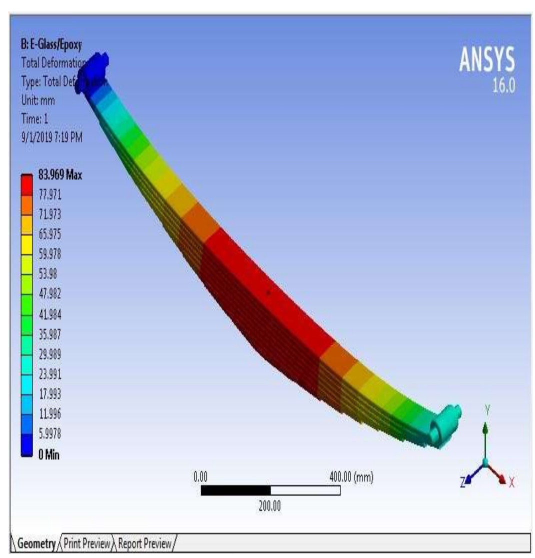

Fig.11. Deformation at 17500 N.

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Table V: Result Comparison at 17500 N

S N	Para-meter	Exp. Results	FEA Results (Steel)	FEA Results (Composite)
1.	Normal Static Load	17500 N	17500 N	17500 N
2.	Deflection	72.5 mm	73.106 mm	83.97 mm
3.	Spring Rate	241.38 N/mm	239.37 N/mm	208.41 N/mm
4.	Maximum Stress	561.5 MPa	620.72 MPa	193.57 MPa

Table VI: Result Comparison at 35000 N

SN	Para-meter	Exp. Results	FEA Results (Steel)	FEA Results (Composite)
1.	Normal Static Load	35000 N	35000 N	35000 N
2.	Deflection	145.5 mm	147.78 mm	165.21 mm
3.	Spring Rate	240.54 N/mm	236.84 N/mm	211.85 N/mm
4.	Bending Stress	1148.5 MPa	1286.9 MPa	397.82 MPa

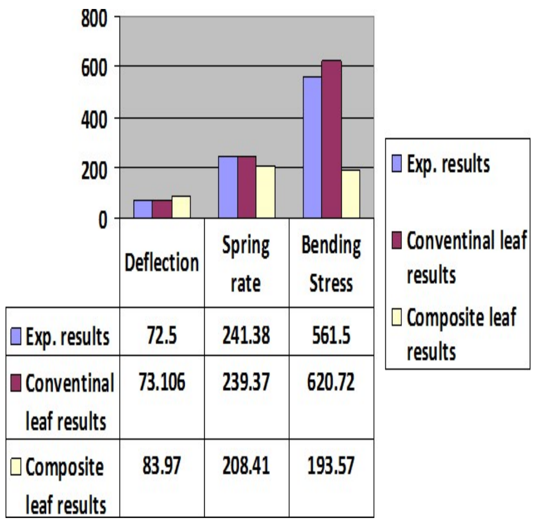

Fig.12. Deflection, spring rate and Bending Stress of composite leaf Spring at 17500 N.

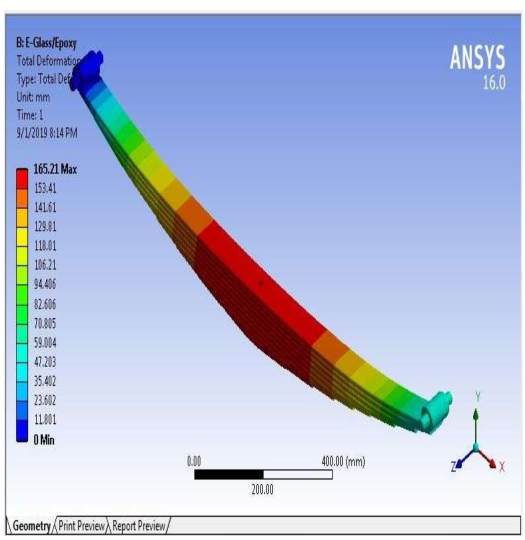

Fig.13. Deformation at 35000 N.

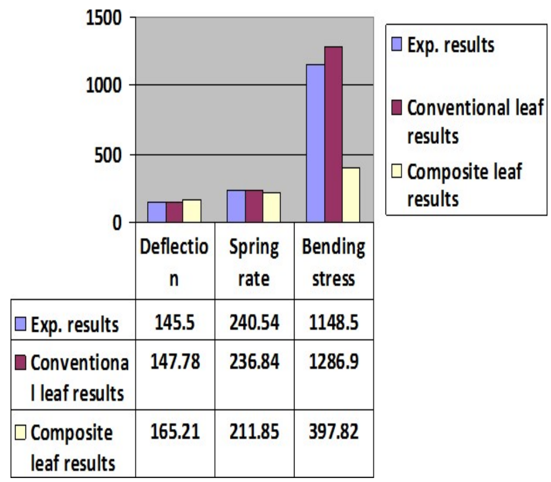

Fig.14. Deflection, spring rate and Bending Stress of composite leaf Spring at 35000 N.

V. CONCLUSION

As automobile world demands research of reducing weight and increasing strength of products, composite material should be up to the mark of satisfying these demands. As leaf spring contributes considerable amount of weight to the vehicle and needs to be strong enough, a single E-Glass/Epoxy composite leaf spring is designed and analyzed following the design rules of composite materials. The 3D model is prepared in Solid works 2016 and then CAE analysis is performed using Ansys 2016 under static loading conditions, from the results obtained from Ansys, many discussions have been made and it will be concluded that:

- A semi-elliptical multi leaf spring is designed for a four wheel automobile and replaced with a composite multi leaf spring made of E-glass/epoxy composites.
- Under the same static loading conditions the stresses and the deflection in leaf springs are found with great difference. Stress in composite leaf springs is found out to be less as compared to the conventional steel leaf springs. Deflection in composite leaf spring is found more as

compared to the conventional steel leaf springs and it absorb more shocks and fluctuation when full load condition.

- All the FEA results are compared with the theoretical and experimental results and it is found that they are within the allowable limits and nearly equal to the theoretical results and experimental.
- A comparative analysis has been made between steel and composite leaf spring with respect to strength and weight ratio. Composite leaf spring reduces the weight by 66.87% for E-Glass/Epoxy.
- E-glass/epoxy composite leaf spring can be suggested for replacing the steel leaf spring both from stiffness and stress point of view.
- Totally it is found that the composite leaf spring is the better that of steel leaf spring. Therefore, it is concluded that composite multi leaf spring is an effective replacement for the existing steel leaf spring in vehicles.

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