Parametric Design and Comparative Analysis of Multi Leaf Spring for Light Automotive Vehicle

Santosh Patel[1], Utkarsh Mansore[2]

[1]Assistant Professor, Dept. of Mechanical Engineering, SVITS, India
[2]B.E. Scholar, Dept. of Mechanical Engineering, SVITS, India

---***---

Abstract - *In now a day the fuel proficiency and outflow gas direction of cars are two essential issues. To satisfy this issue the car enterprises are attempting to make new vehicle which can give high productivity ease. The most ideal approach to build the fuel proficiency is to decrease the heaviness of the vehicle. The weight reduction can be accomplished fundamentally by the presentation of better material, outline streamlining and better assembling forms. The accomplishment of weight reduction with satisfactory change of mechanical properties has made composite a decent substitution material for traditional steel. Leaf springs are one of the most seasoned suspension parts they are still every now and again utilized, particularly in light vehicles. The goal of this paper is to introduce displaying and examination of composite multi leaf spring as an effective alternative to the convention steel suspension system. This text carries out precise results to withstand above statement.*

Key Words: Multi leaf Spring, FEA, Composite, GFRP, CFRP, Epoxy

1. INTRODUCTION

The fuel efficiency and emission gas regulation of automobiles are two important issues. To fulfil 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 Epoxy Resin, Carbon Fiber Reinforced Plastic (CFRP), Glass Fiber Reinforced Plastic (GFRP) are very good replacement material for conventional spring grade steel. In vehicles out of many components of automobile the one which can be easily replaced is leaf spring.

Leaf springs also known as flat spring are made from flat plates. Leaf springs are designed two ways: multi-leaf and mono-leaf. The leaf springs may carry loads, brake torque, driving torque etc. In addition to shocks. The multi-leaf spring is made of several steel plates of different lengths stacked together. During normal operation, the spring compresses to absorb road shock. Leaf spring is made from flat plate. The advantage in 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 the energy absorbing device.

Thus, the leaf springs may carry lateral loads, brake torque, driving torque etc., in addition to shocks. A leaf spring commonly used in automobiles is of semi-elliptical. It is built up of several leaves. The leaves are usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaves are held together by means of a band shrunk around them at the centre or by a bolt passing through the centre. Since the band exerts stiffening and strengthening effect, therefore the effective length of the spring for bending will be overall length of the spring minus width of band. In case of a centre bolt, two-third distance between centres of U-bolt should be subtracted from the overall length of the spring to find effective length. The spring is clamped to the axle housing by means of U-bolts.

Pankaj Saini, Ashish Goel and Dushyant Kumar have studies on analysis of composite leaf spring for light vehicles. In the text, they have considered commercial passenger vehicle with Multi-leaf steel spring of ten leaf for analysis of stress and deflection by using ANSYS 10 Mechanical ADP software. The aim of study is to compare the stresses and load bearing capacity of composite leaf spring with that of steel leaf spring. The material selected was graphite epoxy, E-glass and carbon epoxy which was use against conventional spring grade steel. The dimensions, parameter and the number of leaves for both steel leaf spring and composite leaf springs are the same. Their considered design constraints were stresses and deflections. [1]

M.Venkatesan, D.Helmen, have studied under the same static load conditions stresses and deflection of spring grade steel and composite material multi-leaf springs and found great differences in the parameters. Deflection of composite is less as compared to steel spring with similar loading parameters. The weight of steel leaf spring was found to be 24 kg on the other hand the weight of composite leaf spring was found to be 3.7 kg. Indicating reduction in weight about 80% with same performance level. [2]

2. DESIGN OF LEAF SPRING

A conventional design methods of leaf springs are largely based on the application of empirical literature and semi-

empirical rules along with the use of available information in the existing literature. Leaf springs design depends on load carrying capacity and deflection. Hence the TATA SUMO is considered for design of leaf spring.

2.1 MATERIAL OF LEAF SPRING

Material selected: IS-67SiCr5 (97.28%Fe, 0.72%C, 0.60%Cr, 1.40%Si,), Epoxy Resin, Carbon Fiber Reinforced Plastic (CFRP), Glass Fiber Reinforced Plastic (GFRP).

Table -1: Properties of Convention Spring Grade Steel

Properties	IS-67SiCr5
Young's Modulus	210e+3MPa
Poisson's ratio	0.28
Density	7830kg/m^3
Yield Strength	1100MPa
Tensile Strength	1700MPa
BHN	500-580 HB

Table -2: Properties of Composites

Properties	Epoxy Resin	CFRP	GFRP
E_x (MPa)	43000	177000	294000
E_y (MPa)	6500	10600	6400
E_z (MPa)	6500	10600	6400
PR_{xy}	0.27	0.27	0.23
PR_{yz}	0.06	0.02	0.01
PR_{zx}	0.06	0.02	0.01
G_{xy} (MPa)	4500	7600	4900
G_{yx} (MPa)	2500	2500	3000
G_{zx} (MPa)	2500	2500	3000
Density (t/mm3)	1.14e-9	1.43e-9	1.7e-9
Young's Modulus (MPa)	4940	1.33e+5	10500

2.2 BASIC DATA OF TATA SUMO LEAF SPRING

Table -3: Leaf Spring Specification

Parameter	Value
Total Length of Leaf	1250mm
Number of full length Leaves	2 unit
Number of Graduated Leaves	4 units
Thickness of Leaf	7mm
Width of Leaf	60mm
Total Load	2850kg

Maximum Load = 2850kg = 2850*10 = 28500N

Load acting on the leaf spring assembly = 28500/4 = 7125N

2.3 CALCULATION OF THE LOAD AND EFFECTIVE LENGTH OF LEAF SPRING

Consider the leaf spring is cantilever beam. So, the load acting on each assembly of the leaf spring is acted on the two ends of the leaf spring. Load acted on the leaf spring is divided by the two because of consideration of the cantilever beam.

2*W = 7125N

Effective Load, W = 3562.5N

For support and clamping of the leaf spring the U-bolt is use and the distance between the U-bolts is 110mm. This is considered as an unbent portion of the leaf spring. Ineffective length of the leaf spring is as under:

Effective Length of the spring, L = 588.34mm

Ineffective length = 110mm

2.4 CALCULATIONS OF THE STRESS GENERATED IN THE LEAF SPRING

Property of the conventional steel material are

Tensile Strength = 1700MPa

Yield Strength = 1100MPa

Modulus of Elasticity = 210e+3MPa

BHN = 500 – 580 HB with hardened and tempered

By considering the factor of safety for the safety purpose of the leaf spring is 1.5 for automobile leaf spring. So, the allowable stress for the leaf spring is as under

Tensile Strength = 1700/1.5 = 1133.34MPa

Yield Strength = 1100/1.5 = 733.34MPa

2.5 CALCULATIONS OF THE LENGTH OF LEAVES

$$Length\ of\ smallest\ leaf = \frac{Effective\ length}{n-1} + \frac{2}{3}(Ineffective\ lenght)$$

$$= \frac{2*L}{n-1}*1 + \frac{2}{3}(Ineffective\ lenght)$$

$$= \frac{2 * 588.34}{6 - 1} * l + 73.33 = 308.66 mm$$

$$Length \ of \ 2nd \ leaf = \frac{2 * L}{n - 1} * 2 + \frac{2}{3}(Ineffective \ lenght)$$

$$= \frac{2 * 588.34}{6 - 1} * 2 + 73.33 = 544 \ mm$$

$$Length \ of \ 3rd \ leaf = \frac{2 * L}{n - 1} * 3 + \frac{2}{3}(Ineffective \ lenght)$$

$$= \frac{2 * 588.34}{6 - 1} * 3 + 73.33 = 779.34 \ mm$$

$$Length \ of \ 4th \ leaf = \frac{2 * L}{n - 1} * 4 + \frac{2}{3}(Ineffective \ lenght)$$

$$= \frac{2 * 588.34}{6 - 1} * 4 + 73.33 = 1014.67 \ mm$$

$$Length \ of \ 5th \ leaf = \frac{2 * L}{n - 1} * 5 + \frac{2}{3}(Ineffective \ lenght)$$

$$= \frac{2 * 588.34}{6 - 1} * 5 + 73.33 = 1250 \ mm$$

$$Length \ of \ master \ leaf = 2 * Effective \ Length + \pi(30 + thicknes) * 2$$

$$= 1250 + \pi(30 + 7) * 2 = 1482.48 mm$$

5th and 6th leaves are full length leaves and 6th leaf is known as a master leaf.

2.6 CALCULATION OF SPRING RADIUS

Calculation of radius is as follows

$$camber[(2 * radius) - (camber)] = Effective \ Length^2$$

$$176.26(2 * R - 176.26) = 588.34^2$$

$$Radius \ of \ Curvature \ of \ Spring, R = 1196.22 mm$$

3. MODELLING AND ASSEMBLY

The parametric designs are prepared with the help of CAD software namely Autodesk® Inventor™ 2018 on student license subscription over compatible PC workstation. There are different procedures available for modeling of leaf spring. Here we utilize divisional method of generation of parabolic leaf spring. The sheet metal in ANSI code conduct is used with specific width and thickness as defined above. The sheet metal is hemming to form upturn eye with 30mm internal diameter and a camber with 176.26mm. Similarly, 5 more leaf are formed and constrained together to form a multi leaf spring as shown below.
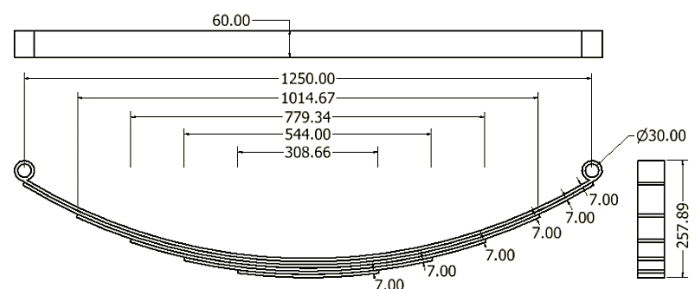

Fig-1: Multi Leaf Spring Assembly

Fig-2: Multi Leaf Spring Specifications

4. FINITE ELEMENT ANALYSIS

FEA (Finite Element Analysis) 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 too many 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 FEA has following advantages.

- Increased Virtualization and Capabilities
- Times Saving
- Robust and Simplified

A. Pre-processing

The pre-processing comprises of varies fundamental arguments, conditions and constraints are defined about which the results are required. The part is subdivided to cell and unit elements called Meshing. Mesh 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. Furthermore, boundary condition is defined for providing specific relational conditions so that optimum and accurate results can be obtained. Boundary condition also enable user to reduce complexity and enable further accuracy to the results.

B. Solver

The condition and constrains created turn the model meshing to mathematical complex model and been resolved to get raw data in terms of physical quantities.

C. Post-processing

The acquired raw data is turned into useful information. Furthermore, this information is the base for providing user defined results and parameters.

The FEA analysis is carried out on Autodesk® Nastran™ In-Cad 2018.

4.1 BOUNDARY CONDITION AND MESHING

Meshing involves division of the entire of model into small pieces called elements. It is convenient to select the free mesh because the leaf spring has sharp curves, so that shape of the object will not alter. The goal of meshing in is to provide robust, easy to use meshing tools that will simplify the mesh generation process. These tools have the benefit of being highly automated along with having a moderate to high degree of user control. To mesh the leaf spring the element type must be decided first. Here, the element type is solid 45 and element order is parabolic. The element edge length is taken as 15 mm. The numbers of elements are taken 16488 and the total numbers of nodes are 36820 as shows in Fig. 3.

Initial assumptions for the analysis:

- Model simplification for FEA.
- Meshing size is limited to computer compatibilities.
- Static analysis is considered.
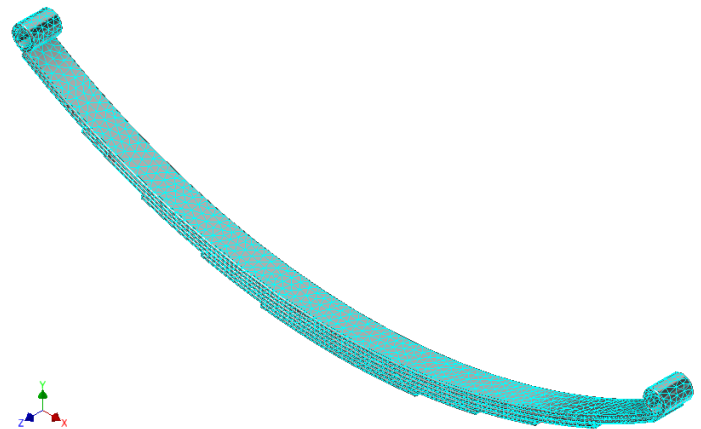- Material used for conventional leaf spring analysis is isotropic

Fig-3: Parabolic Meshing of Spring Assembly

Fixed Support For the leaf spring analysis one of the eye ends of the leaf spring is fixed to the chassis of the vehicle. Since fixed support has restriction to move in X and Y direction as well as rotation about that fixed point. So, this fixed eye end of the leaf spring cannot move in any of the directions i.e. for this eye end degrees of freedom are zero. Cylindrical support since the leaf spring must translate in one plane and other movements are restricted to move as there is shackle provided at other end of the leaf spring. Therefore, a cylindrical support is applied to the other eye end of leaf spring model.
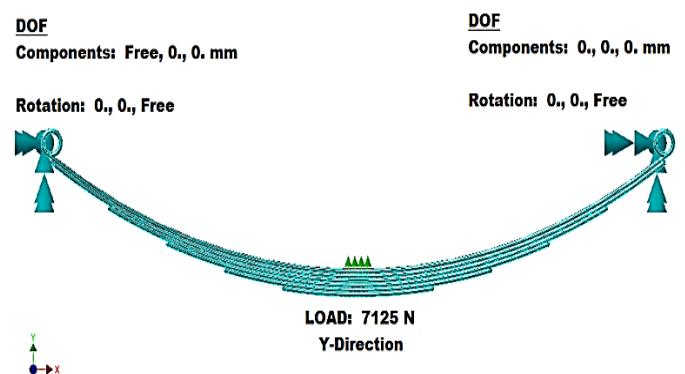

Fig-4: Load and Constraints of Spring Assembly

This support provides the movement of the leaf spring in X axis, rotation about Z axis and fixed along Y axis. The load is uniformly distributed on the leaf spring. In this study uniformly, distributed load of 7125N is applied on the leaf spring model.

4.2 SURFACE CONTACTS WITHIN LEAFES OF SPRING

The surface contacts within Convention material i.e., IS-65SiCr5 is "NO SEPERATION/ SLIDING" and surface contact within composite material is "BONDED". This is considered so because of the manufacturing ease and compatibility.

4.3 STATIC ANALYSIS OF LEAF SPRING

The static analysis id carried out over the a series of load from 2000N to 7000N for the sake of better understanding and information along with the maximum load capacity of 7125N.
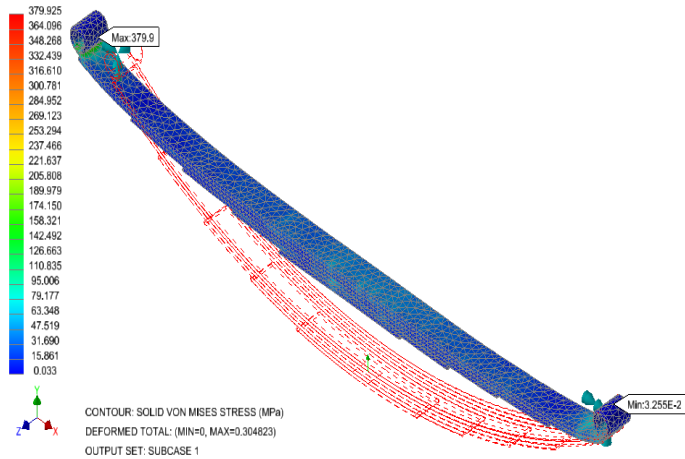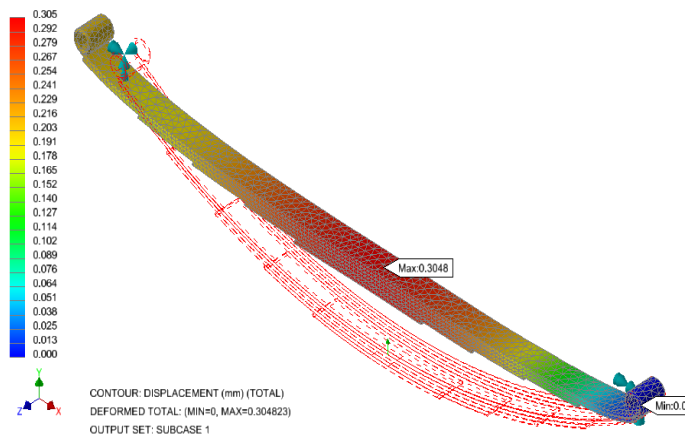

Fig-5: Von-Mises Stress of IS-65SiCr5
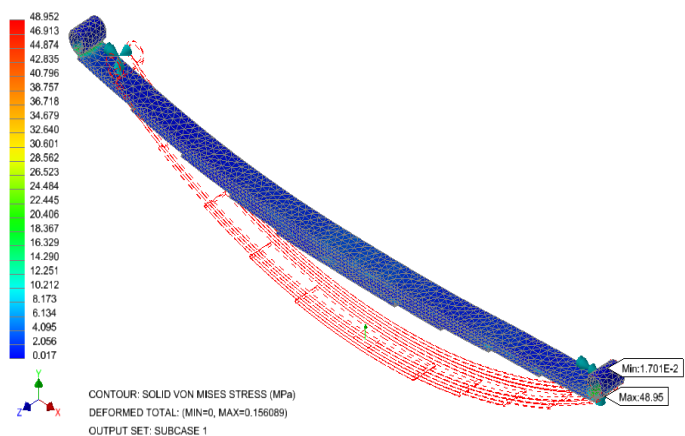

Fig-6: Displacement of IS-65SiCr5

Fig-7: Von-Mises Stress of Carbon Fiber Reinforced Plastic
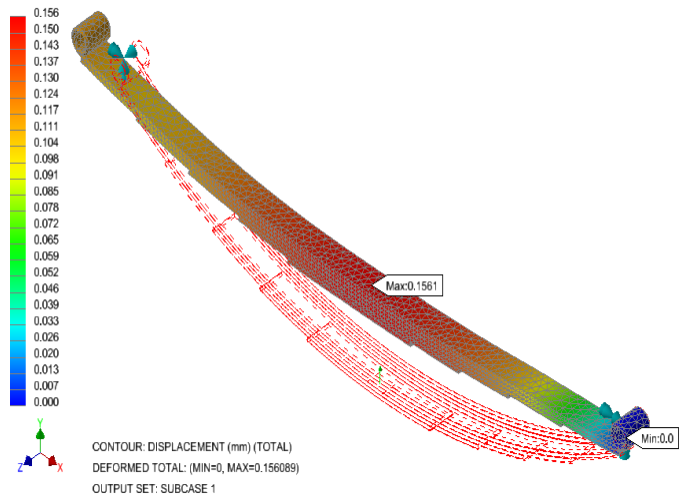

Fig-8: Displacement of Carbon Fiber Reinforced Plastic
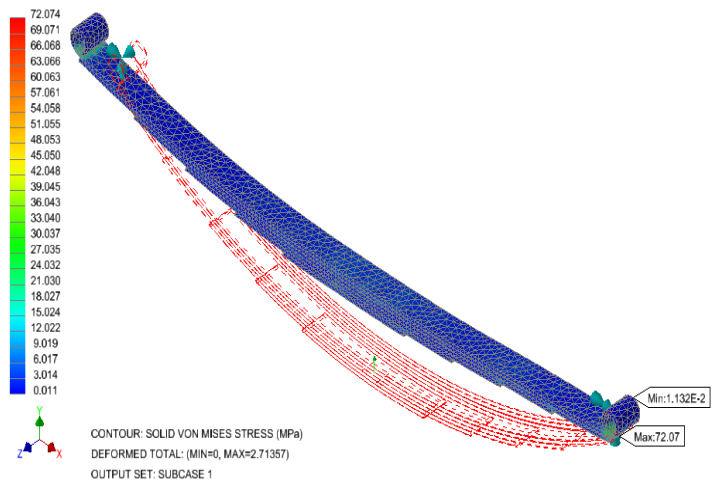

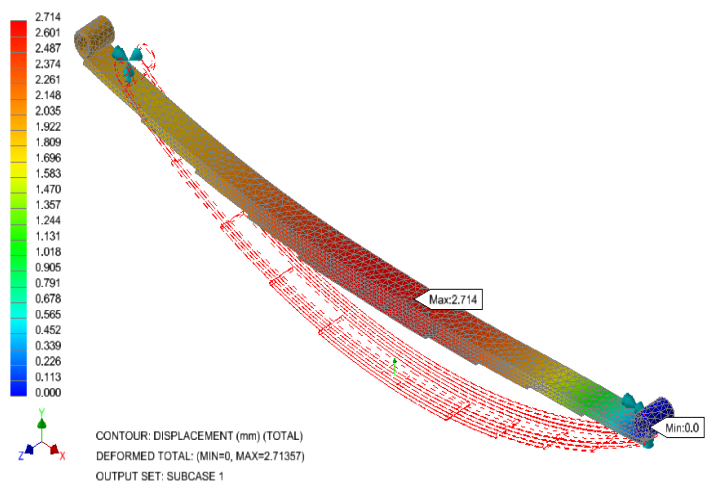**Fig-9**: Von-Mises Stress of Glass Fiber Reinforced Plastic
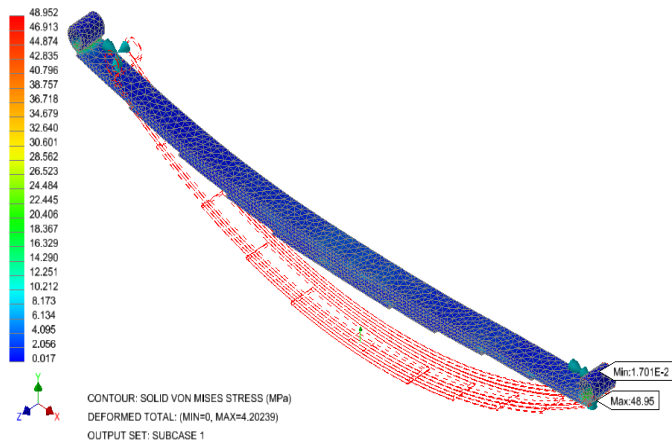

Fig-10: Displacement of Glass Fiber Reinforced Plastic
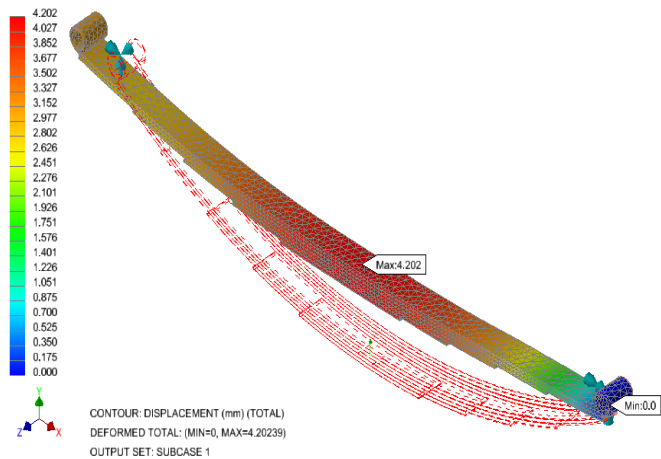
Fig-11: Von-Mises Stress of Epoxy resin
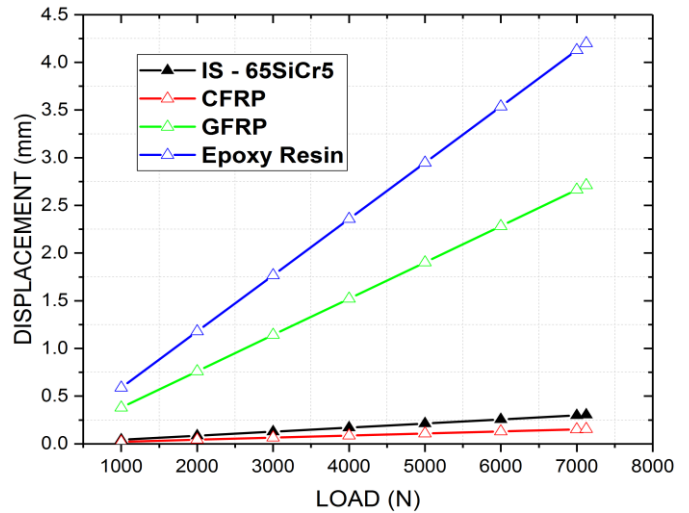

Fig-12: Displacement Stress of Epoxy resin

4. COMPARISION AND RESULTS

Fig-13: Von-Mises Stress comparison

Fig-14: Displacement comparison

Table -1: Von-Mises Stress at serial Load

Load (N)	IS-65SiCr5	CFRP	GFRP	Epoxy Resin
1000	53.323	6.870	10.116	6.870
2000	106.647	13.741	20.231	13.741
3000	159.971	20.612	30.347	20.612
4000	213.292	27.482	40.463	27.482
5000	266.612	34.352	50.578	34.352
6000	319.935	41.222	60.693	14.222
7000	373.260	48.093	70.809	48.093
7125	379.925	48.952	72.094	48.952

Table -2: Displacement at serial load

Load (N)	IS-65SiCr5	CFRP	GFRP	Epoxy Resin
1000	0.043	0.022	0.381	0.590
2000	0.086	0.044	0.762	1.180
3000	0.128	0.066	1.143	1.769
4000	0.171	0.088	1.523	2.359
5000	0.214	0.110	1.904	2.949
6000	0.257	0.131	2.285	3.539
7000	0.029	0.153	2.660	4.129
7125	0.305	0.156	2.715	4.202

Table -3: Percentage Weight Reduction

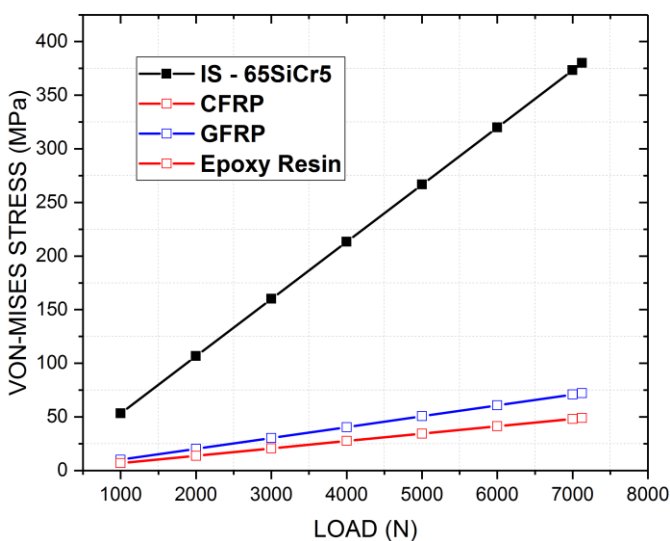| Material	Weight	Percentage Reduction
IS – 65SiCr5	18.013kg	0
CFRP	3.281kg	81.79%
GFRP	3.901kg	78.35%
Epoxy Resin	2.616kg	85.48%

Hence from the above, it is observed that, by using the Carbon Fiber Reinforced Plastic (CFRP), Glass Fiber Reinforced Plastic (GFRP), Epoxy Resin materials for leaf spring more deflection can be obtained with reduced in the spring weight. The conventional multi leaf spring weights about 18.013 kg whereas the Epoxy Resin multi leaf spring weighs only 2.616 kg. Thus, the maximum weight reduction of 85.48% is achieved. By the reduction of weight and the less stresses, the fatigue life of Epoxy Resin leaf spring is to be higher than that of steel leaf spring. Totally it is found that the Epoxy Resin leaf spring is the better that of steel leaf spring.

5. CONCLUSIONS

A steel grade Multi leaf Spring can be replaced by Epoxy Resin, Carbon Fiber Reinforced Plastic (CFRP), Glass Fiber Reinforced Plastic (GFRP) leaf spring due their high strength to weight ratio for the same load carrying capacity with same dimension as that of steel leaf spring. A semi-elliptical multi leaf spring is designed for a four-wheel automobile and replaced with composite multi leaf spring made of Epoxy Resin, Carbon Fiber Reinforced Plastic (CFRP) and Glass Fiber Reinforced Plastic (GFRP).

By the comparative study of conventional steel and composite leaf spring the maximum bending stress developed in the steel leaf spring is 379.925MPa, Glass Fiber Reinforced Plastic (GFRP) is 72.092MPa and Carbon Fiber Reinforced Plastic (CFRP) and Epoxy Resin is 48.952MPa at given loading condition. Stress in composite leaf springs is found out to be less as compared to the conventional steel leaf springs.

Under the same static load conditions, the deflection in composite Epoxy Resin and Glass Fiber Reinforced Plastic (GFRP) leaf springs is found with great difference of 3.897mm and 2.41mm respectively compared to conventional steel. The deflection in Carbon Fiber Reinforced Plastic (CFRP) is found to be 0.419mm less than the conventional steel spring. The deflection in epoxy Resin leaf springs is found out to be high as compared to the conventional steel leaf springs.

The maximum weight savings of 85.48% is achieved by replacing Composite Epoxy Resin with conventional spring grade steel IS-65SiCr5.

Overall, it is found that the Epoxy Resin, Carbon Fiber Reinforced Plastic (CFRP), Glass Fiber Reinforced Plastic (GFRP) are better material than conventional spring grade steel. Therefore, it is concluded that a composite multi leaf spring is effective replacement for the existing steel leaf spring.

6. FUTURE SCOPE

A. TRANSIENT ANALYSIS OF LEAF SPRING

Since the study and analysis of composite leaf spring has begun at a rapid pace, it's the need of the time to kick start the transient analysis for the same now. Hence this analysis may be conducted to see how the composite leaf spring behaves when seen in a transient atmosphere

B. MANUFACTURING OF COMPOSITE LEAF SPRING

This structural analysis of both the steel and composite leaf spring indicates that the later one is far better than the former one and produces even better results; hence its manufacturing should start which will reduce the flaws and improve the efficiency of the vehicle.

6. REFERENCES

[1] Pankaj Saini, Ashish Goel, Dushyant Kumar, "Design and analysis of composite leaf spring for light vehicles", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 5, May 2013

[2] M. Venkatesan, D.Helman, "Design and analysis of composite leaf spring in light vehicle", International Journal of Modern Engineering and Research, Vol. I, Issue I, 2012, p213-218

[3] J.P. Hou, J.Y. Cherruault, I. Nairne, G. Jeronimidis, R.M. Mayer, "Evolution of the eye-end design of a composite leaf spring for heavy axle loads", Composite Structures, Issue.78, 2007, p351–358.

[4] Kumar Krishan, Aggarwal M.L, "Computer aided FEA comparison of mono steel and mono GRP leaf spring",International Journal of Advanced Engineering Research and Studies, Vol. I, Issue II, 2012, pp 155-158.

[5] M. M. Patunkar, D. R. Dolas, "Modelling and Analysis of Composite Leaf Spring under the Static Load Condition by using FEA", International Journal of Mechanical & Industrial Engineering, Volume 1, Issue 1, 2011.

[6] Vinkel Arora, Dr. M. L. Aggarwal, Dr. Gian Bhushan,"A Comparative Study of CAE and Experimental Results of Leaf Springs in Automotive Vehicles", International Journal of Engineering Science and Technology, Vol. 3, No. 9, 2011.

[7] Mr. Anandkumar A. Satpute, Prof. S. S. Chavan, "Mono Composite Leaf Spring – Design and Testing", Indian Journal of Applied Research, Volume 3, Issue 7, 2013.

[8] R. N. Kalwaghe, Prof. K.R. Sontakke "Design and Analysis of Composite Leaf Spring by Using Fea and ANSYS" International Journal of Scientific Engineering and Research (IJSER) ISSN (Online): 2347-3878

[9] R.S. Khurmi and J.K. Gupta, "Machine design", First ed., Eurasia Publishing House, 2005, p866-879