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DESIGN AND ANALYSIS OF COMPOSITE LEAF SPRING FOR LIGHT VEHICLES

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ABSTRACT: - Reducing weight while increasing or maintaining strength of products is getting to be highly important research issue in this modern world. Composite materials are one of the material families which are attracting researchers and being solutions of such issue. In this paper we describe design and analysis of composite leaf spring. The objective is to compare the stresses and weight saving of composite leaf spring with that of steel leaf spring. The design constraint is stiffness. The Automobile Industry has great interest for replacement of steel leaf spring with that of composite leaf spring, since the composite materials has high strength to weight ratio, good corrosion resistance. The material selected was glass fiber reinforced polymer (E-glass/epoxy), carbon epoxy and graphite epoxy is used against conventional steel. The design parameters were selected and analyzed with the objective of minimizing weight of the composite leaf spring as compared to the steel leaf spring. The leaf spring was modeled in Auto-CAD 2012 and the analysis was done using ANSYS 9.0 software.
Keywords: - stiffness, composite leaf spring, steel leaf spring, ANSYS 9.0, Auto-CAD 2012.

I. INTRODUCTION

Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. It carries lateral loads, brake torque, driving torque in addition to shock absorbing [1]. The advantage of 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 to energy absorbing device [2]. According to the studies made a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring [3].

To meet the need of natural resources conservation, automobile manufacturers are attempting to reduce the weight of vehicles in recent years [4]. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The suspension leaf spring is one of the potential items for weight reduction in automobiles un-sprung weight. This achieves the vehicle with more fuel efficiency and improved riding qualities. The introduction of composite materials was made it possible to reduce the weight of leaf spring without any reduction on load carrying capacity and stiffness [5].

For weight reduction in automobiles as it leads to the reduction of un-sprung weight of automobile. The elements whose weight is not transmitted to the suspension spring are called the un-sprung elements of the automobile. This includes wheel assembly, axles, and part of the weight of suspension spring and shock absorbers. The leaf spring accounts for 10-20% 0f the un-sprung weight [6]. The composite materials made it possible to reduce the weight of machine element without any reduction of the load carrying capacity. Because of composite material's high elastic strain energy storage capacity and high strength-to-weight ratio compared with those of steel [7],[8]. FRP springs also have excellent fatigue resistance and durability. But the weight reduction of the leaf spring is achieved not only by material replacement but also by design optimization.

Weight reduction has been the main focus of automobile manufacturers in the present scenario. The replacement of steel with optimally designed composite leaf spring can provide 92% weight reduction. Moreover the composite leaf spring has lower stresses compared to steel spring. All these will result in fuel saving which will make countries energy independent because fuel saved is fuel produced.

II. AIM AND SCOPE OF THE WORK

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The objective of the present work is to design, analyze and propose a method of fabrication of composite mono-leaf spring for automobile suspension system. This is done to achieve the following-

- This design helps in the replacement of conventional steel leaf springs with composite mono-leaf spring with better ride quality.
- To achieve substantial weight reduction in the suspension system by replacing steel leaf spring with mono composite leaf spring.

III. DESCRIPTION OF THE PROBLEM

The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the un-sprung weight [9]. The introduction of composites helps in designing a better suspension system with better ride quality if it can be achieved without much increase in cost and decrease in quality and reliability [7]. The relationship of the specific strain energy can be expressed as it is well known that springs, are designed to absorb and store energy and then release it slowly. Ability to store and absorb more amount of strain energy ensures the comfortable suspension system. Hence, the strain energy of the material becomes a major factor in designing the springs. The relationship of the specific strain energy can be expressed as [15]

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

Where σ is the strength, ρ is the density and E is the Young's Modulus of the spring material.

It can be easily observed that material having lower modulus and density will have a greater specific strain energy capacity. The introduction of composite materials made it possible to reduce the weight of the leaf spring without reduction of load carrying capacity and stiffness due to more elastic strain energy storage capacity and High strength to weight ratio.

A. *DEMERITS OF CONVENTIONAL LEAF SPRING* ([1], [4],][5],[7]..)

- They have less specific modulus and strength.
- Increased weight.
- Conventional leaf springs are usually manufactured and assembled by using number of leafs made of steel and hence the weight is more.
- Its corrosion resistance is less compared to composite materials.
- Steel leaf springs have less damping capacity.

B. *MERITS OF COMPOSITE LEAF SPRING [1-13]*

- Reduced weight.
- Due to laminate structure and reduced thickness of the mono composite leaf spring, the overall weight would be less.
- Due to weight reduction, fuel consumption would be reduced.
- They have high damping capacity; hence produce less vibration and noise.
- They have good corrosion resistance.

- They have high specific modulus and strength.
- Longer fatigue life.

C. ASSUMPTIONS

- All non-linear effects are excluded.
- The stress-strain relationship for composite material is linear and elastic; hence Hooke's law is applicable for composite materials
- The leaf spring is assumed to be in vacuum.
- The load is distributed uniformly at the middle of the leaf spring.
- The leaf spring has a uniform, rectangular cross section.

IV. SELECTION OF CROSS SECTION

The following cross-sections of mono-leaf spring for manufacturing easiness are considered.

- Constant thickness, varying width design
- Varying width, varying thickness design.
- Constant thickness, constant width design

In the present work, only constant cross-section design method is selected due to the following reasons: due to its capability for mass production and accommodation of continuous reinforcement of fibers. Since the cross-section area is constant throughout the leaf spring, same quantity of reinforcement fiber and resin can be fed continuously during manufacturing [7].

V. MATERIALS FOR LEAF SPRING

The material used for leaf springs is usually a plain carbon steel having 0.90 to 1.0% carbon. The leaves are heat treated after the forming process. The heat treatment of spring steel products greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties[14].

Carbon/Graphite fibers: Their advantages include high specific strength and modulus, low coefficient of thermal expansion and high fatigue strength. Graphite, when used alone has low impact resistance. Its drawbacks include high cost, low impact resistance and high electrical conductivity [14].

Glass fibers: The main advantage of Glass fiber over others is its low cost. It has high strength, high chemical resistance and good insulating properties. The disadvantages are low elastic modulus poor adhesion to polymers, low fatigue strength and high density, which increase leaf spring weight and size. Also crack detection becomes difficult [14].

VI. SPECIFIC DESIGN DATA

Here Weight and initial measurements of Mahindra "Model - commander 650 di" light vehicle are taken [16].

Gross vehicle weight = 2150 kg

Unsprung weight = 240 kg

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Total sprung weight = 1910 kg

Taking factor of safety (FS) = 1.4

Acceleration due to gravity (g) = 10 m/s²

There for; Total Weight (W) = 1910*10*1.4 = 26740 N

Since the vehicle is 4-wheeler, a single leaf spring corresponding to one of the wheels takes up one fourth of the total weight.

F = 26740/4 = 6685 N

A. DESIGN PARAMETERS OF STEEL LEAF SPRING

Leaf no.	**Full leaf length (mm) 2L**	**Half leaf length(mm) L**	**Radius of curvature R (mm)**
1	1120	560	961.11
2	1120	560	967.11
3	1007	503.5	973.11
4	894	447	979.11
5	780	390	985.11
6	667	333.5	991.11
7	554	277	997.11
8	440	220	1003.11
9	327	163.5	1009.11
10	214	107	1015.11

Since the leaf spring is fixed with the axle at its center, only half of it is considered for analysis purpose with half load.

VII. INTRODUCTION OF FINITE ELEMENT SOFTWARE

The Basic concept in FEA is that the body or structure may be divided into smaller elements of finite dimensions called “Finite Elements”. The original body or the structure is then considered as an assemblage of these elements connected at a finite number of joints called “Nodes” or “Nodal Points”. Simple functions are chosen to approximate the displacements over each finite element. Such assumed functions are called “shape functions”. This will represent the displacement within the element in terms of the displacement at the nodes of the element. Mathematically, the structure to be analyzed is subdivided into a mesh of finite sized elements of simple shape. Within each element, the variation of displacement is assumed to be determined by simple polynomial shape functions and nodal displacements. Equations for the strains and stresses are developed in terms of the unknown nodal displacements. From this, the equations of equilibrium are assembled in a matrix form which can be easily be programmed and solved in software. After applying the appropriate boundary conditions, the nodal displacements are found by solving the matrix stiffness equation. Once the nodal displacements are known, element stresses and strains can be calculated.

A. SOLID MODELING

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 and a uniformly distributed load is applied over the ineffective length of the leaf spring in the upward direction.

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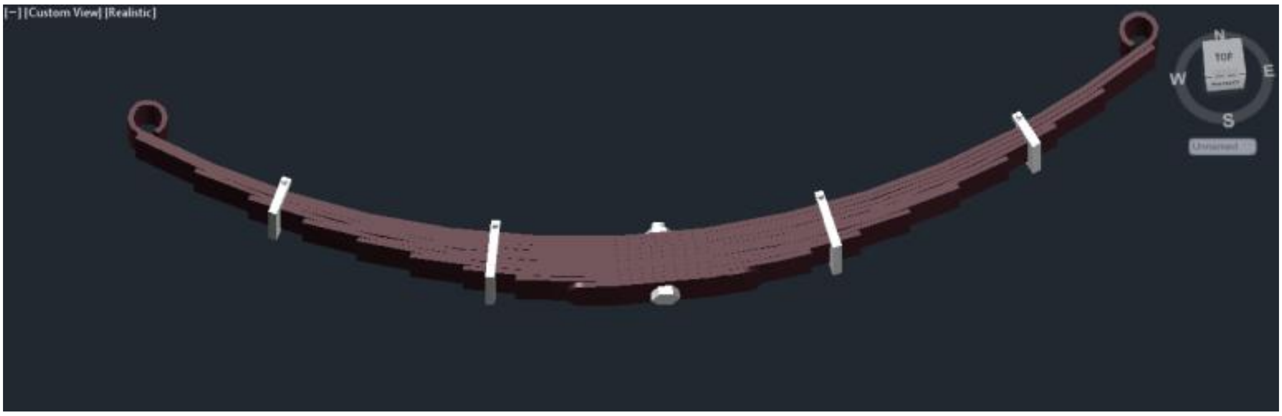

Fig.1: -Solid model of steel leaf spring created in auto CAD 2012 and imported its half portion for analysis in ANSYS 9.0.

B. ELEMENT TYPE

- •SOLID45- 3D Structural Solid
- • CONTA174 - 3D 8-Node Surface-to-Surface Contact

SOLID45 is used for the 3-D modeling of solid structures. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.
CONTA174 is an 8-node element that is intended for general rigid-flexible and flexible-flexible contact analysis. CONTA174 is surface-to-surface contact element. CONTA174 is applicable to 3D geometries. It may be applied for contact between solid bodies or shells.

VIII. SPECIFICATIONS OF STEEL LEAF SPRING

Specifications		
1	Total Length of the spring (Eye to Eye)	1120mm
2	Free Camber (At no load condition)	180mm
3	No. of full length leaves	2
4	No. of graduated leaves	8
5	Thickness of leaf	6mm
6	Width of leaf spring	50mm
7	Maximum Load given on spring	6685N
8	Young's Modulus of the steel	210000 (MPa)
9	Weight of the leaf spring	17.78 kg
10	Poisson's ratio	0.3

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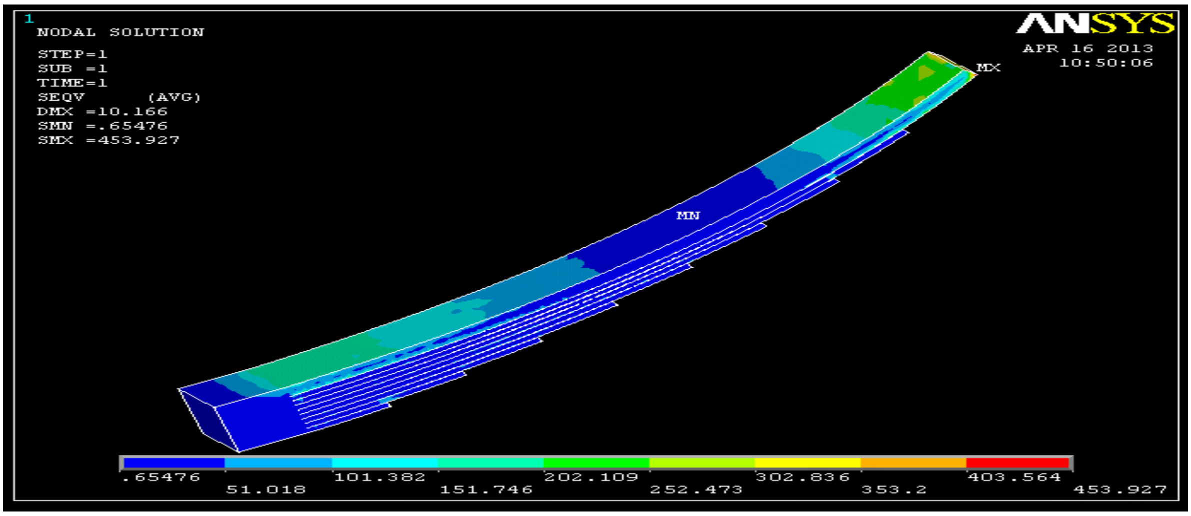

Fig.2- Plot of vonmises stresses of steel leaf spring

IX. SPECIFICATIONS OF COMPOSITE LEAF SPRINGS

Material	**Half length (mm)**	**Width (mm)**	**Thickness (mm)**	**Radius of Curvature(mm)**
Carbon/ epoxy	560	50	14	961.11
Graphite/epoxy	560	50	12	961.11
E-Glass/epoxy	560	50	22	961.11

A. ORTHOTROPIC PROPERTIES OF COMPOSITES

Sr. no.	**Properties**	**E-glass/epoxy**	**Carbon epoxy**	**Graphite epoxy**
1	EX(MPa)	43000	177000	294000
2	EY(MPa)	6500	10600	6400
3	EZ(MPa)	6500	10600	6400
4	PRXY	.27	.27	.023
5	PRYZ	.06	.02	.01
6	PRZX	.06	.02	.01
7	GX (MPa)	4500	7600	4900
8	GY(MPa)	2500	2500	3000
9	GY(MPa)	2500	2500	3000
10	ρ (kg/mm^3)	.000002	.0000016	.00000159

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X. RESULTS AND DISCUSSION

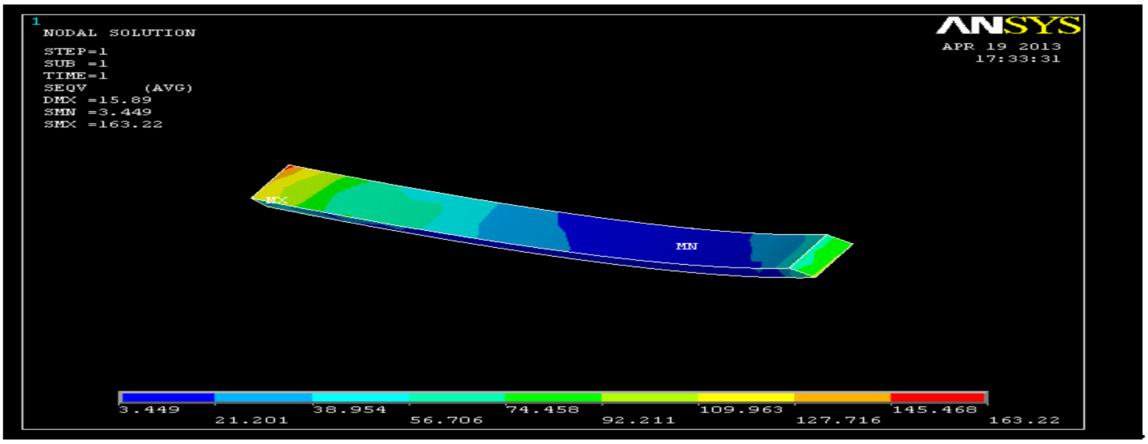

Fig.3- Von-mises stresses of GFRP leaf spring

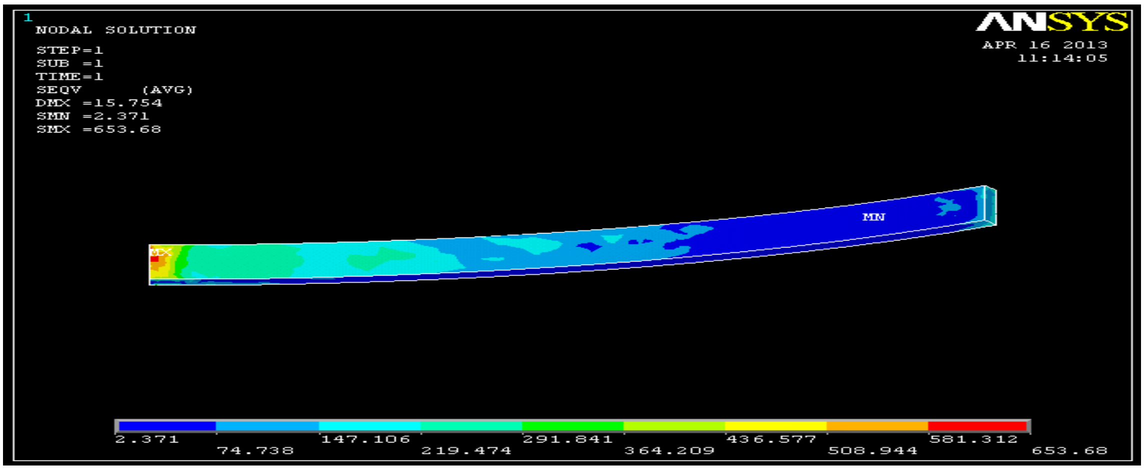

Fig.4- Von-mises stresses of Graphite leaf spring

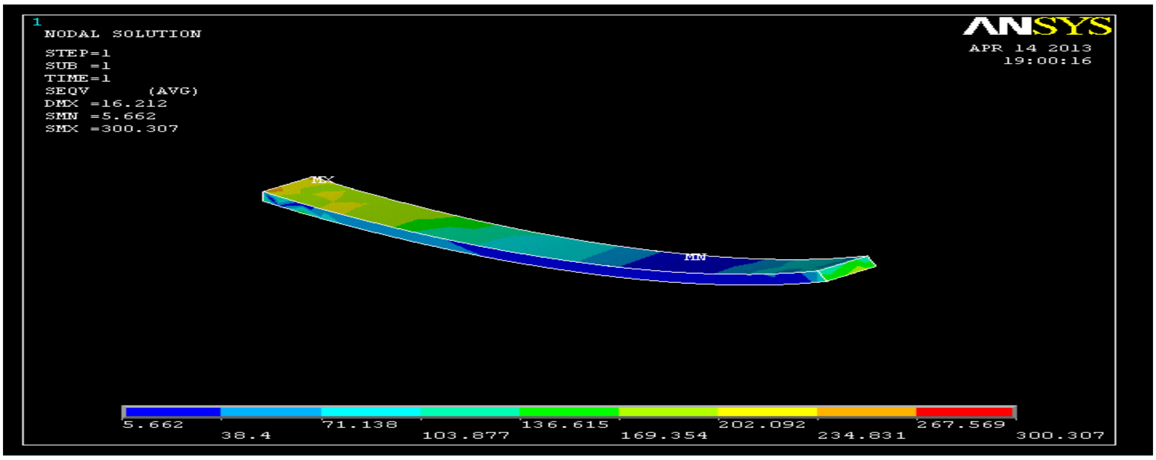

Fig.5- Von-mises stresses of CFRP leaf spring

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Static analysis has been performed using ANSYS, fig 3 to 5 shows the vonmises stresses plot for composite leaf springs. In the present work, a steel leaf spring was replaced by a mono composite leaf spring due to high strength to weight ratio for the same load carrying capacity and stiffness. The dimensions of a leaf spring of a light weight vehicle are chosen and modeled using auto CAD 2012 and simulation is performed using ANSYS 9.0. As the leaf spring is symmetrical about the axis, only half part of the spring is modeled by considering it as a cantilever beam. Analysis has been performed by using ANSYS by applying the boundary conditions and the load. The boundary conditions are UY, UZ at the front eye end and UX, UZ in the middle. A uniformly distributed load of 67N/mm was applied over the ineffective length of the leaf spring in the Y-direction. Later a mono composite leaf spring of uniform thickness and width was modeled so as to obtain the same stiffness as that of steel leaf spring. Three different composite materials have been used for analysis of mono-composite leaf spring. They are E-glass/epoxy, Graphite/epoxy and carbon/epoxy. The results from the plots tabled below.

The table shows the displacement and stresses for same loading condition.

Materials	**Displacement (mm)**	**Stress (MPa)**
Steel	10.16	453.92
Graphite epoxy	15.75	653.68
Carbon epoxy	16.21	300.3
E-glass epoxy	15.89	163.22

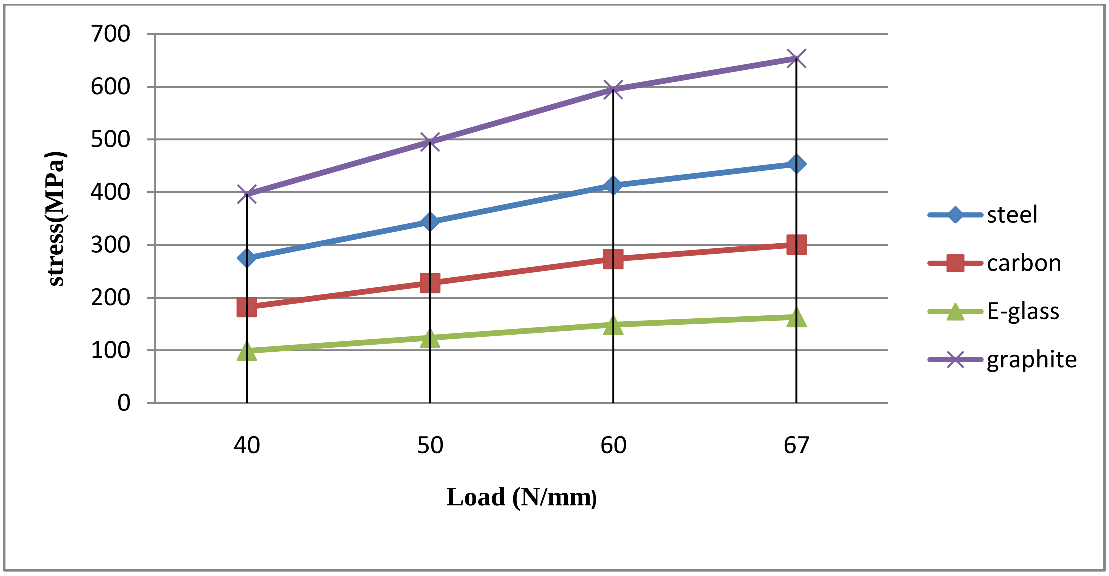

Fig.6: Stress Vs Load

From above plot and tabel we can see that the value of stress in E-glass is minimum and displacement is approximately equal for all the composites.

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A. PERCENT WEIGHT SAVING

Table shows the % saving of weight by using composites instead off steel.

	Materials	**% weight saving**
1	Steel	-
2	E-glass/epoxy	81.72
3	Carbon epoxy	90.51
4	Graphite epoxy	91.91

XI. CONCLUSION

As reducing weight and increasing strength of products are high research demands in the world, composite materials are getting to be up to the mark of satisfying these demands. In this paper reducing weight of vehicles and increasing the strength of their spare parts is considered. As leaf spring contributes considerable amount of weight to the vehicle and needs to be strong enough, a single composite leaf spring is designed and it is shown that the resulting design and simulation stresses are much below the strength properties of the material satisfying the maximum stress failure criterion.

From the static analysis results it is found that there is a maximum displacement of 10.16mm in the steel leaf spring and the corresponding displacements in E-glass / epoxy, graphite/epoxy, and carbon/epoxy are 15.mm, 15.75mm and 16.21mm. And all the values are below the camber length for a given uniformly distributed load 67 N/mm over the ineffective length.

From the static analysis results, we see that the von-mises stress in the steel is 453.92 MPa. And the von-mises stress in E-glass/epoxy, Graphite /epoxy and Carbon/epoxy is 163.22MPa, 653.68 MPa and 300.3 MPa respectively. Among the three composite leaf springs, only graphite/epoxy composite leaf spring has higher stresses than the steel leaf spring.

E-glass/epoxy composite leaf spring can be suggested for replacing the steel leaf spring from stress and stiffness point of view.

A comparative study has been made between steel and composite leaf spring with respect to strength and weight. Composite mono leaf spring reduces the weight by 81.22% for E-Glass/Epoxy, 91.95% for Graphite/Epoxy, and 90.51 % for Carbon/Epoxy over conventional leaf spring.

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