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Design and Analysis Of Mono Composite Leaf Spring For Suspension in Automobiles

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Abstract

Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and strength of composite materials. The automobile industry has shown increased interest in the replacement of steel spring with fiberglass composite leaf spring due to high strength to weight ratio. This work deals with the replacement of conventional steel leaf spring with a Mono Composite leaf spring using E-Glass/Epoxy. 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 Pro/E and the analysis was done using ANSYS Multiphysics software.

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. 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.

The automotive industry is exploiting composite material technology for structural components construction in order to obtain the reduction of weight without decrease in vehicle quality and reliability. To conserve the natural resources and economize energy, weight reduction has been the main focus of automobile manufacturer in the present scenario. Actually, there is almost a direct proportionality between the weight of the vehicle and its fuel consumption, particularly in city driving. The advanced composite materials such as Graphite, Carbon, Kevlar and Glass with suitable resins are widely used because of their high specific strength (strength/density) and high specific modulus (modulus/density). Advanced composite materials seem ideally suited for suspension (leaf spring) applications. Their elastic properties can be tailored to increase the strength and reduce the stresses induced during application.

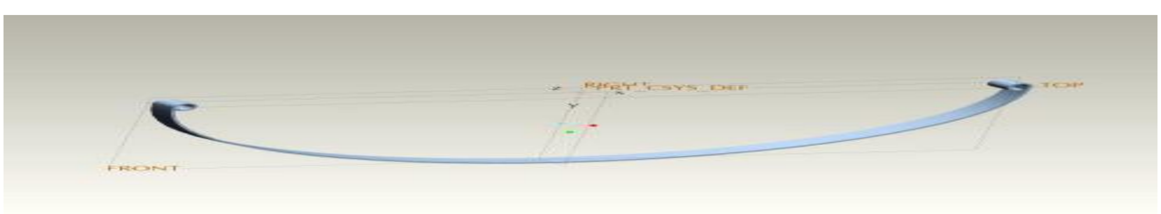


Figure 1 monoleaf spring

Aim and scope of the work

The objective of the present work is to design, analyze and propose a method of fabrication of E-Glass/Epoxy mono composite 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 E-glass/Epoxy 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.

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 unsprung weight. 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. In the design of springs, strain energy becomes the major factor. The relationship of the specific strain energy can be expressed as

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

Where σ the strength is 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 the following factors of composite materials as compared to steel.

More elastic strain energy storage capacity and

High strength-to-weight ratio.

Design of Composite Mono Leaf Spring

Considering several types of vehicles that have leaf springs and different loads on them, various kinds of composite leaf spring have been developed. In the case of multi-leaf composite leaf spring, the interleaf spring friction plays a spoil spot in damage tolerance. It has to be studied *carefully. The following cross-sections of mono-leaf spring for manufacturing easiness are considered.*

- *Constant thickness, constant width design*
- *Constant thickness, varying width design*
- *Varying width, varying width design.*
- *In the present work, only a mono leaf spring with constant thickness, constant width design is analyzed. The design parameters to be optimized are*
- *Ply thickness*
- *Number of plies required*
- *Stacking sequence of Laminate*

Modeling and Analysis

- *Modeling of Steel leaf spring and E-Glass/Epoxy composite leaf spring using Pro-E*
- *Modeling of C-Channel and Bracket using Pro-E*
- *Static analysis of Steel leaf springE-Glass/Epoxy composite mono leaf spring, using ANSYS software.*
- *Modal analysis of Steel and E-Glass/Epoxy composite mono leaf spring to find the natural frequency so as to investigate the ride quality.*

Demerits of Conventional Leaf Spring

- *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.*

Merits of Composite Leaf Spring

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

Specification of the problem

The objective of the present work is to design, analyze and propose a method of fabrication of unidirectional E-Glass/Epoxy complete mono composite leaf spring with Berlin Eye for automobile suspension system and compare it with a steel leaf spring with same dimensions for mechanical behavior characteristics. The actual conditions were simulated and the composite structure is analyzed for maximum force inputs to the leaf spring due to bumps on the road.

Assumptions

- *The leaf spring has a uniform, rectangular cross section.*
- *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.*
- *Acoustical fluid interactions are neglected, i.e., the leaf spring is assumed to be in vacuum.*
- *The load is distributed uniformly at the middle of the leaf spring.*

Determining Geometries for Leaf Spring

After studying the effect of leaf spring geometric variables (the width, thickness, and length of each leaf, and the total number of leaves) on the stress and deflection of the leaf spring. Table 1 lists the design implications for the design of leaf spring.

Table 1 Design Implications of Various Leaf Springs' Geometric Variables.

Geometric variable	Design implication
Leaf length (L)	Use largest possible L
Leaf thickness (h)	Use smallest h that will provide an acceptable value for stress
Leaf width (w)	Use smallest w that will provide sufficient spring deflection

After studying several leaf spring manufacturers' data, we learned that the most commonly manufactured leaf spring widths are 63, 75, and 90 millimeters. Consequently, these widths are less expensive to manufacture; thus, we chose to consider only these widths in our leaf spring designs. Table 2 shows standard sizes for Leaf Spring width and thickness.

For our analysis we chose to use the combination of a leaf thickness of 9.0 mm and a leaf width of 75 mm keeping the leaf length at 1000 mm for semi-elliptical leaf spring and 800 mm for cantilever leaf spring. These dimensions were chosen for analysis because they are the most popular ones and easier to be manufactured.

Table 2 Standard Sizes for Leaf Springs (millimeters).

Widths		Thicknesses					
40.0	75.0	5.00	7.10	10.00	14.00	20.00	28.00
45.0	90.0	5.30	7.50	10.60	15.00	21.20	30.00
50.0	100.0	5.60	8.00	11.20	16.00	22.40	31.50
56.0	125.0	6.00	8.50	11.80	17.00	23.60	33.50
63.0	150.0	6.30	9.00	12.50	18.00	25.00	35.50
		6.70	9.50	13.20	19.00	26.50	37.50

Spring Eyes

A spring eye is essentially the end of a leaf spring bended into a circular shape to allow rotation about the spring eye. The main types of spring eye designs are upturned, military wrapper, down turned, and Berlin eyes (see Figure 2).

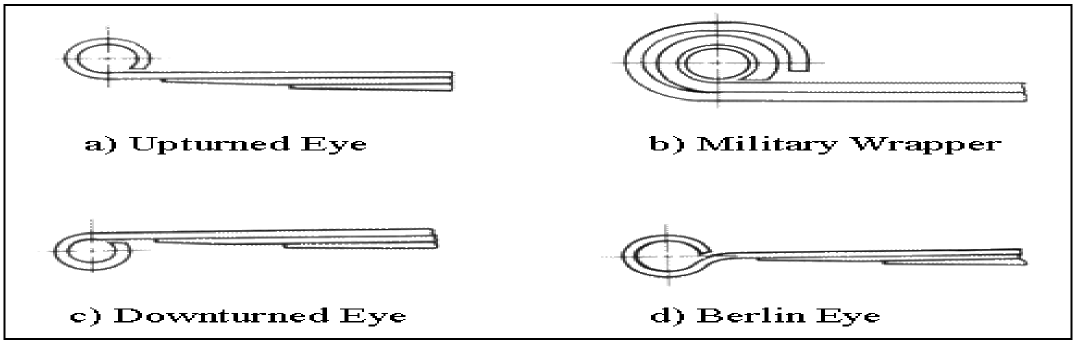


Figure2 Types of Spring Eyes

The main concern with a spring eye is its tendency to unwrap (to deform from its circular shape). Once the stress in the spring eye exceeds the yield strength of the leaf spring material, the eye will unwrap. To calculate the stress in a particular spring eye, the following formula is used:

$$S = \frac{3F(D+t)}{t^2 w}$$

where S = stress, F = applied force, D = inner diameter of spring eye,

t = leaf thickness, and w = leaf width. (SAE, 1982)

Upturned eyes are the most commonly used type of spring eye because of their simple design and high durability. Upturned eyes are highly durable because they resist stress due to vertical forces on a suspension system. Unlike other spring eye designs, an upturned eye applies vertical loads on the linear leaf section that was not bent to form the eye. Therefore, upturned eyes have less of a tendency to unwrap as result of vertical forces than the other types of spring eyes (SAE, 1982).

For cantilever and semi-elliptical leaf spring design, Berlin's eye is used to constrain the chassis front axle. The geometry of a Berlin eye reduces the tendency of the spring eye to unwrap when a vehicle experiences longitudinal loads (loads directed in the direction of travel). Berlin eyes apply longitudinal loads centrally to the main leaf, thereby reducing the tendency of the spring eye to unwrap for longitudinal loading (SAE, 1982). The cantilever leaf springs of front suspension system design will experience relatively high longitudinal loads when the vehicle encounters large obstacles. For this reason, Berlin eyes were used for the cantilever leaf springs of front suspension system design.

Free Ends of Leaf Spring

Semi-elliptic leaf springs can also be mounted to a vehicle's frame via a free end. A free end of a leaf spring is simply a flat section of the main leaf. The movement of the free end is usually constrained only in the vertical direction by a bracket, which allows the free end to move in the horizontal direction as the leaf spring deflects due to forces from the terrain. As the leaf spring deflects, the Coloumbic friction associated with the free end sliding past the bracket adds damping to the suspension system. For rear suspension system, this damping is desirable because it eliminates the need of an expensive shock absorber. Because of the damping associated with using a free end, the back end of the semi-elliptic leaf spring was attached to the chassis frame via a free end.

Selection of Cross-Section

Due to manufacturing ease, uniform rectangular cross section is considered and analyzed here.

Selection of Reinforcement Fiber

Fibers are available with widely differing properties. Review of the design and performance requirements usually dictate the fibers to be used.

***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.*

***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*

***Kevlar fibers**: The advantages include low density, high tensile strength, low cost and higher impact resistance. The disadvantages are very low compressive strength, marginal shear strength and high water absorption. Kevlar is not recommended for load carrying application because of its low strength in compression and shear.*

Here Glass fibers are selected as potential materials for the design of leaf spring.

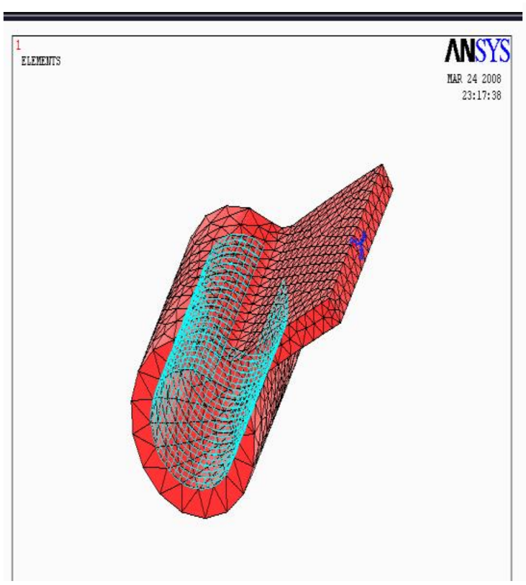
Finalization of Composite Material

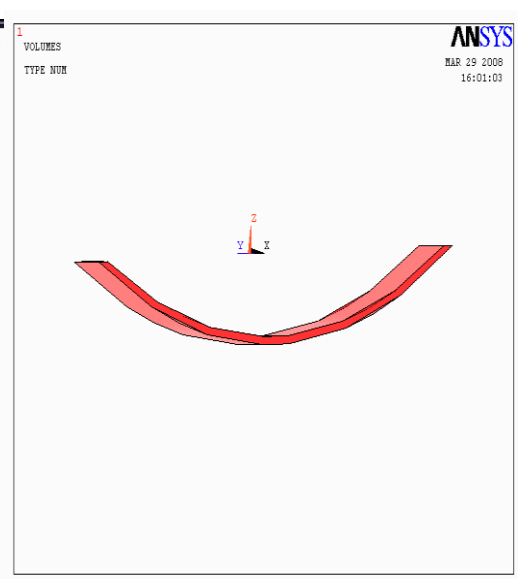
Based on the advantages discussed earlier, the E-Glass/Epoxy material is selected. The table shows the properties of the E-glass/Epoxy material used for the design of mono composite leaf spring.

S.No.	Symbol	Units	Value
1	E_x	Mpa	34000
2	E_y	Mpa	6530
3	E_z	Mpa	6530
4	S_t	Mpa	900
5	S_c	Mpa	450
6	G_{xy}	Mpa	2433
7	G_{yz}	Mpa	1698
8	G_{zx}	Mpa	2433
9	ν_{xy}	-	.217
10	ν_{yz}	-	.366
11	ν_{zx}	-	.217
12	ρ	Kg/mm^3	2.6e-6

Table-3 Properties of E-Glass/Epoxy,

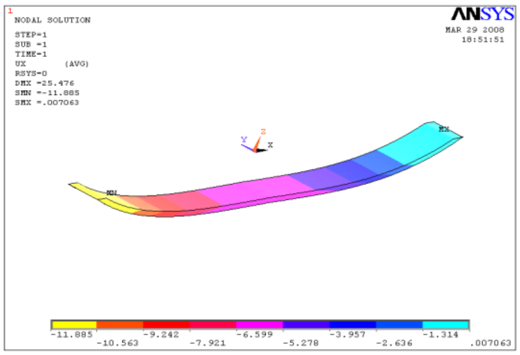
Modeling:

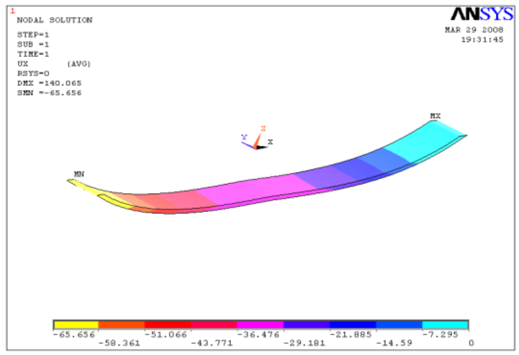




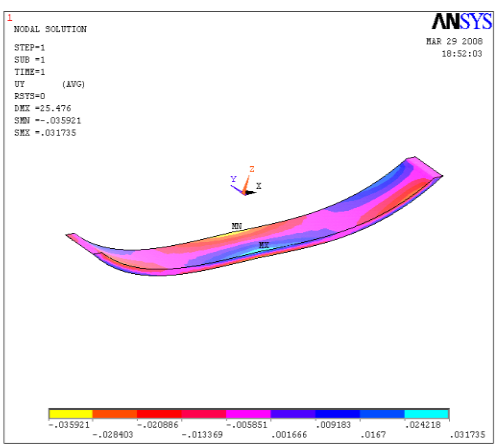
Results and Discussions **Contour Plots Leaf Spring (Static Analysis)**

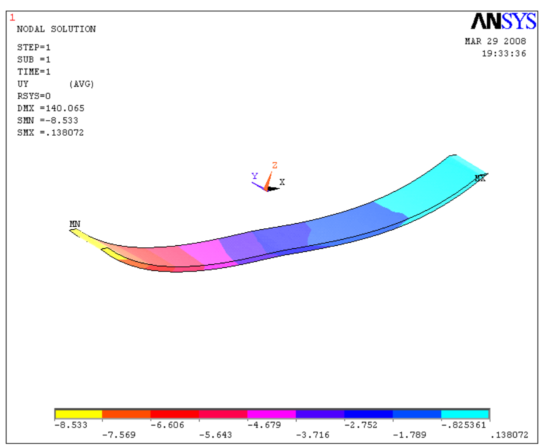
Displacement



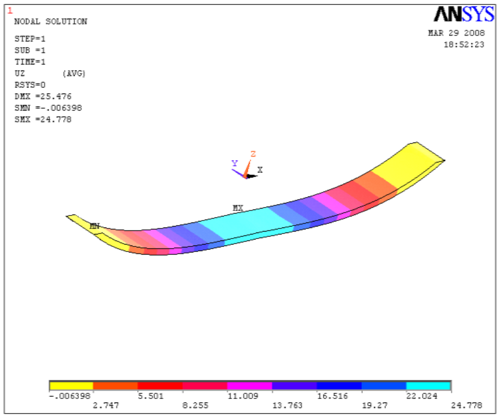


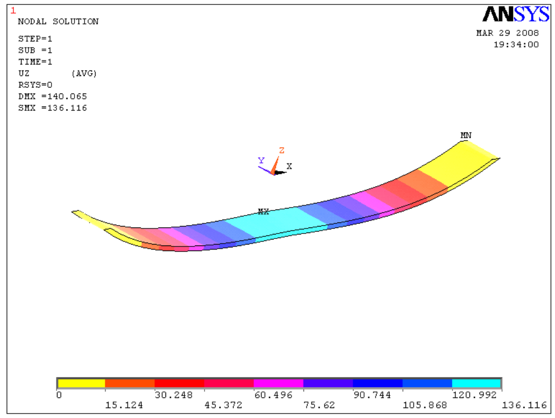
X Component of Displacement (Steel) X Component of Displacement (Composite)





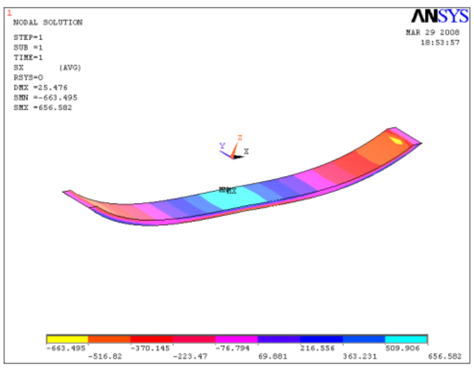
Y Component of Displacement (Steel) Y Component of Displacement (Composite)

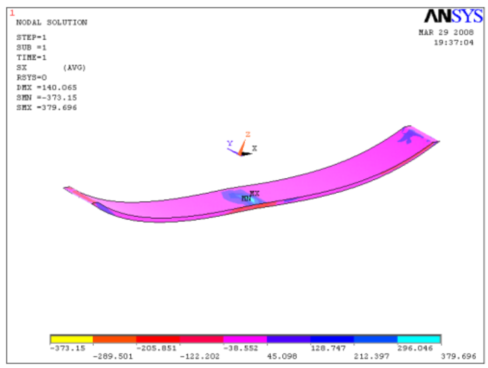




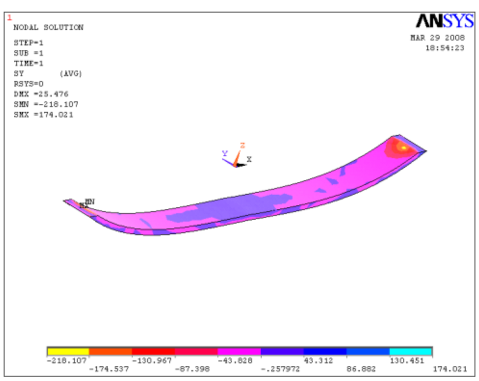
Z Component of Displacement (Steel) Z Component of Displacement (Composite)

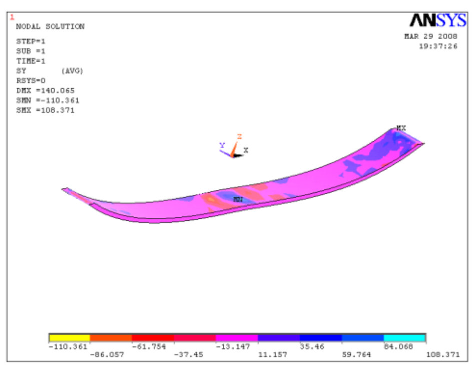
Stresses



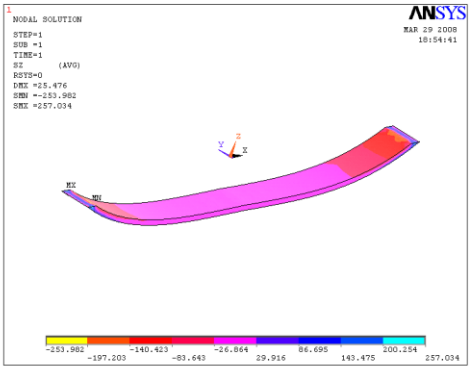


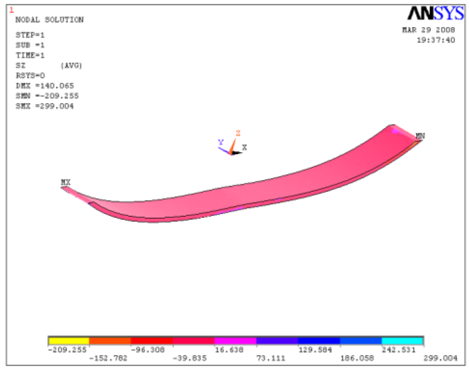
X Component of Stress (Steel) X Component of Stress (Composite)





Y Component of Stress (Steel) Y Component of Stress (Composite)





Z Component of Stress (Steel) Z Component of Stress (Composite)

Stress in Leaf Spring

Material	**Mechanical Property**	**Allowable Stress (Mpa)**	**Maximum Stress obtained (Mpa)**	**Factor of Safety**	**Design**
Steel (55Si2Mn90)	Yield Strength	1470	758.162	1.94	OK
E-Glass/Epoxy	Tensile Strength	900	382.228	2.35	OK
	Compressive Strength	450	382.228	1.18	OK

Stress in Upturned Eye

Material	**Mechanical Property**	**Allowable Stress (Mpa)**	**Maximum Stress obtained (Mpa)**	**Factor of Safety**	**Design**
Steel (55Si2Mn90)	Yield Strength	1470	72.569	20.25	OK
E-Glass/Epoxy	Tensile Strength	900	46.56	19.33	OK
	Compressive Strength	450	23.91	18.82	OK

Deflection in Leaf Spring

Material	**Maximum Deflection (mm)**

Steel (55Si2Mn90)	25.476
E-Glass/Epoxy	140.065

Comparison of Leaf Spring Masses (without eye)

Material	Volume (m^3)	Density (kg/ m^3)	Mass
Steel	860.056e-6	7600	6.536
E-Glass/Epoxy	703.177e-6	2600	1.828

Mode Shapes and Frequencies

Material	Frequency				
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Steel (55Si2Mn90)	1.239	1.763	4.983	7.827	10.05
E-Glass/Epoxy	0.635	1.235	3.742	3.777	6.931

The following conclusions were drawn from the present work

- *The E-Glass/Epoxy mono composite leaf spring was modeled and analyzed to replace the conventional steel leaf spring in the suspension system of automobiles.*
- *A mono composite leaf spring for the vehicular suspension system was designed using E-Glass/Epoxy with the objective of minimization of weight of the leaf spring subjected to constraints such as type of loading and laminate thickness and ply orientation angle.*
- *By analyzing the design, it was found that all the stresses in the leaf spring were well within the allowable limits and with good factor of safety.*
- *It was found that the longitudinal orientations of fibers in the laminate offered good strength to the leaf spring. The optimum stacking sequence was unidirectional along the longitudinal direction of the leaf spring.*
- *From the stress results of leaf spring eye, it was observed that due to large factor of safety, the eye will not unwrap during loading.*
- *It was observed that the composite leaf spring weighed only 27.96 % of the steel leaf spring for the analyzed stresses. Hence the weight reduction obtained by using mono composite leaf spring as compared to steel was 72.04 %.*

- *It was observed that the deflection in the composite leaf spring was much greater than that of steel. It allows for greater flexibility and control. Hence the chassis for the vehicle with composite leaf spring should be assembled at a distance of at least 150 mm from the axle seat to avoid collision of leaf spring with the vehicle chassis during loading.*
- *Ride quality is generally quantified as the natural frequency of a suspension system. Suspension system natural frequencies less than 1 Hz will cause motion sickness in a vehicle's passengers, and suspension system natural frequencies greater than 2.5 Hz will provide a "harsh" ride. In the present work, the 2nd mode shape of the mono composite leaf spring has a natural frequency of 1.235 Hz which provides for good ride quality.*