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Analysis of Composite Leaf Spring Enhanced With Nanoparticles

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Abstract: Weight reduction is now the main issue in automobile industries. In this work due to reduce the weight of steel spring with composite leaf spring due to high strength ratio is need to improve. The main aim is to compare to the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring at rated-load and over-load condition. The analysis has been carried out for the leaf spring made up of steel and Composite materials. Composite specimens are fabricated with two different staking sequences like the (resin with clay and enhanced with Nanoparticles). The thickness and width for constant cross section is maintained on the moulding techniques. The design of multi leaf spring was modeled in PRO-E and imported in ANSYS 14.5.the dimensions of an existing multi leaf spring is taken for modeling and analysis of a laminated composite multi leaf spring with different composite sequence materials subjected to the same load as that of steel spring.

Keywords: Leaf spring, BinaniFiber, Epoxy, and Nano clay

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1 Introduction: A leaf spring is a simple form of spring commonly used for the suspension in wheeled vehicles. Leaf spring is very common in Light and Heavy duty vehicles in automobiles and more sophisticated suspension designs saw automobile manufactures use coil springs instead. A leaf spring takes the form of slender arc-shaped length of spring steel of rectangular cross-section. The center of the arc provides location for the axle, while tie holes are provided at either end for the attaching to the vehicle body. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves. Leaf spring can serve locating and to some extent damping as well as springing functions. While the interleaf friction provides a damping action, it is not well controlled and results in the motion of the suspension system. The manufactures have experimented with mono-leaf springs.

Today leaf springs are still used in heavy commercial vehicles such as vans, cars, trucks and railway carriage. Leaf springs are also located the rear axle, eliminating the need for trailing arm and pan hard rod. There by saving cost and weight in a sample live axle rear suspension. A further advantage of a leaf spring over a helical spring is that the end of the leaf spring may be guided along a definite path. A more modern implementation is the parabolic leaf spring. This design is characteristic by fewer leaves whose thickness varies from centre to ends following a parabolic curve. Aside from a weight saving the main advantage of parabolic leaf spring is their greater flexibility which translates into vehicle ride quality the approaches that of coil springs. There is a trade-off in the form of reduced loads carrying capability. The characteristics of parabolic springs are better riding comfort and not as 'stiff' as conventional multi-leaf springs. It is widely used on buses for better comfort.

2. Literature Review: The review papers are mainly referred to reducing the weight of steel leaf spring with composite leaf spring made of the fiber materials and majority of the published work applies to them.

J.P. Hou, **[1]** design evolution process of a composite leaf spring for freight rail applications. Three designs of eye-end attachment for composite leaf springs are described. The material used is glass fiber reinforced polyester. Static testing and finite element analysis have been carried out to obtain the characteristics of the spring. Load–deflection curves and strain measurement as a function of load for the three designs tested have been plotted for comparison with FEA predicted values. The main concern associated with the first design is the delamination failure at the interface of the fibres that have passed around the eye and the spring body, even though the design can withstand 150 KN static proof load and one million cycles fatigue load. FEA results confirmed that there is a high interlaminar shear stress concentration in that region. The second design feature is an additional transverse bandage around the region prone to delamination. Delamination was contained but not completely prevented. The third design overcomes the problem by ending the fibres at the end of the eye section.

Mahmood M. Shokrieh, **[2]** Analyzes a four-leaf steel spring used in the rear suspension system of light vehicles using ANSYS V5.4 software. The finite element results showing stresses and deflections verified the existing analytical and experimental solutions. Using the results of the steel leaf spring, a composite one made from fiberglass with epoxy resin is designed and optimized using ANSYS. Main consideration is given to the optimization of the spring geometry. The objective was to obtain a spring with minimum weight that is capable of carrying given static external forces without failure. The results showed that an optimum spring width decreases hyperbolically and the thickness increases linearly from the spring eyes towards the axle seat. Compared to the steel spring, the optimized composite spring has stresses that are much lower, the natural frequency is higher and the spring weight without eye units is nearly 80% lower.

C. Subramanian, **[3]** Joint strength plays a significant role in the performance of leaf spring suspension system. Current work reported the influence of reinforced fiber length on the performance of injection molded thermoplastic leaf spring joint. Leaf springs were molded using 20% short, long glass fiber reinforced polypropylene as well as unreinforced polypropylene and evaluated for the joint strength. Servo hydraulic test facility with suitable fixture is utilized to evaluate the leaf spring joint performance under static and dynamic conditions. Test joints were subjected to completely reversed fatigue loads, wherein long fiber reinforced leaf spring joint exhibited superior performance at high cycle fatigue conditions than that of short fiber reinforced and unreinforced polypropylene leaf spring joints. However, at low cycle fatigue loading conditions, unreinforced and short glass fiber reinforced leaf spring exhibited superior performance than that of long glass fiber reinforced leaf spring joint. High notch sensitivity characteristics of the long glass fiber reinforced polypropylene material contributed to this inferior performance. Load–deflection hysteresis plot of the long glass fiber reinforced leaf spring joint under fatigue loading conditions exhibited a lesser amount of hole elongation compared to that of short glass fiber and unreinforced leaf spring joint. Failure morphology of tested joint under fatigue condition exhibited net-tension and shear-out failures besides bearing damages.

Amol Bhanage, **[4]** Describes that the steel leaf spring used in passenger cars is replaced with a composite leaf spring made of a glass/epoxy composite The primary objective is to compare fatigue characteristics of SAE1045-450-QT steel and E -Glass/ Epoxy Composite material. Based on the available design data a fatigue analysis is carried out on an ANSYS Workbench v14.0 and the results of the simulation are documented. Factors like fatigue life, fatigue damage, biaxialy indication, rain flow counting and fatigue response are plotted for the composite leaf spring and the fatigue performance is predicted using life data. Therefore the presented work a design and simulation studied on the fatigue performance of a glass fibre/epoxy composite leaf spring through design and finite element method and prove that reliability of the validation methods based only on simulation, thereby saving time, material and production costs for a completed product realization.

Dara Ashok, **[5]** done their work to design and structural analysis of composite leaf spring made of glass fiber reinforced polymer (GFRP). Leaf spring consist two full length leaves in which one is with eyed ends and five graduated length leaves. The material of the conventional leaf spring is 65Si7. The material for the composite leaf spring is E-Glass/Epoxy unidirectional laminates or GFRP. Dimensions of the composite leaf spring are to be taken as the same dimensions of the conventional leaf spring for modeling. The objective is to compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. The finite element modeling and analysis of a multi leaf spring has been carried out. The FE model of the leaf spring has been generated in Pro-E 4.0 and imported in ANSYS-11 for finite element analysis, which are most popular CAE tools. 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 **[6 - 11]**.

3 Problem Definition: The objective of the present work is to design the composite material of leaf spring (Binani Fiber NanoClay/Epoxy) for automobile Suspension system and analyze it. This is done to achieve the following. To reduce the conventional steel leaf springs with (Binani Fiber NanoClay/Epoxy) composite leaf spring. To achieve substantial weight reduction in the suspension system by replacing steel leaf spring with Nanocomposite leaf spring.

4 Specification of conventional Material: Leaf spring is a low-alloy, medium-carbon steel 65Si7 with very high yield strength. This allows objects made of spring steel to return to their original shape despite significant bending or twisting. Nickel is the key component to most spring steel alloys. The most widely used spring steel is ASTM A228 (0.80%-0.95% carbon).

Table (1): Chemical Composition of 65Si7

Grade	C%	Si%	Mn%	P%	S%	Cr%
65Si7	0.51-0.62	0.15-0.35	0.65-0.95	0.035	0.035	0.65-0.95

Table (2): Mechanical properties of 65Si7 leaf spring

Parameters	Value
Length of the first leaf	1275 mm
Length of the second leaf	1150 mm
Length of the third leaf	965 mm
Width of all leaves	45 mm
Thickness of the leaf	7 mm
Young's modulus E	2.1x105N/mm2
Poisson Ratio	0.266
Tensile strength	450MPa
Density	0.00000785Kg/mm3
Behavior	Isotropic

5 Selection of Composite Material: A composite material is made by combining two or more materials-often ones that have very different properties. The two materials work together to give the composite unique properties. However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other. Most composite are made of just two materials. One is the matrix or binder. It surrounds and binds together fibers or fragments of the other material, which is called reinforcement. The primary functions of the matrix are to transfer stresses between the reinforcing fibers and protect the fibers from mechanical and/or environmental damages. The basic requirement of the matrix material is that its strain at break must be larger than the fibers it is holding. The reinforcing phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger and stiffer than the matrix. The reinforcement is usually a fiber or a particulate. The continuous phase is called as the matrix that is always a metal, polymer or a ceramic.

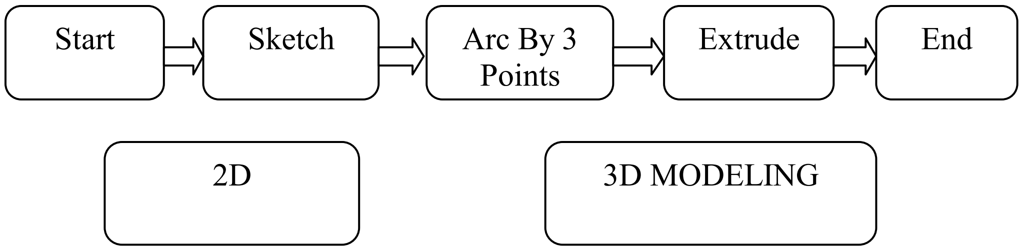
Table (3): Mechanical properties of BinaniFiber/ Epoxy

Properties	Value
Tensile modulus along X-Direction (Ex),Mpa	130508.93
Tensile modulus along Y Direction (Ex),Mpa	13242
Tensile modulus along Z Direction (Ex),Mpa	13242
Poisson ratio along XY-Direction (NUxy)	0.217
Poisson ratio along YZ-Direction (NUxy)	0.326
Poisson ratio along XZ -Direction (NUxy)	0.29
Tensile strength at yield, MPa	1781.44
Tensile strength at Break, MPa	919.29
% of Elongation	1.88
Mass density of the material, kg/mm3	2.6e-6
Behavior	orthotropic

6. Modeling: Pro-engineer is a parametric, integrated 3D CAD/CAM/CAE solution created by parametric technology corporation (PTC). It was the first successful, parametric, featured-based, associative solid modeling software on the market. The application run on Microsoft Window, Linux and Unix platforms, and provides solid modeling, assembly modeling and drafting, finite element analysis, and NC and too along functionality foe mechanical engineer.

Generally for modeling, packages likes pro-Engineer, IDEAS will be used. In his analysis the model is created in the ANSYS itself to eliminate the data losses that will occur if standard data exchange formats like IGES, STEPS are used. To create the model the details about the key point locations are taken as the inputs.

6.1 Leaf Spring Modeling Flowchart:



6.2 3D Modeling of the Leaf Spring: The model of the prototype leaf spring is shown in the figure below. The length of the leaf spring is about 1275 mm. the Arc height of the Axle is 125 mm. the width and thickness of leaf spring is taken as 45 mm and 7 mm.

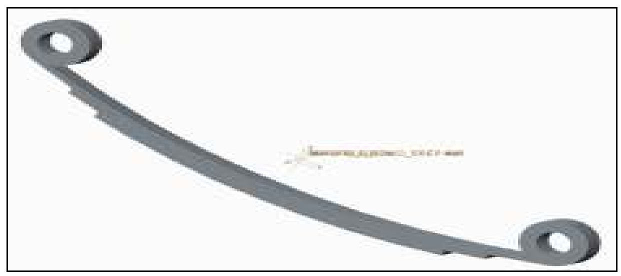


Figure (1): 3D Modeling of Leaf Spring.

The cross section of the leaf spring is created on the sketch plane and then it is extruded to the length of 965mm and the visible and the invisible edges are rounded off and the thus the leaf spring is modeled. Initially the leaf spring is saved under the extension of .prt and then in order to import the 3 dimensional model into the other analysis background the file extension .prt is converted into the neutral file format of extension .iges thus it can be imported into any type of the analysis software environment.

6.2.1 Meshing of the Leaf spring Model: Meshing involves division of the entire of model into small pieces called elements. This is done by meshing. It is convenient to select the free mesh because the leaf spring has sharp curves, so that shape of the object will not alter. To mesh the leaf spring the element type must be decided first. Here, the element type is solid 72. Fine mesh is created with 16916 nodes and 2212 elements. After meshing is done the contacts and targets must be defined in between individual leafs of the leaf spring (figure 2). The material properties of the given leaf spring are given in table 2 and table 3.

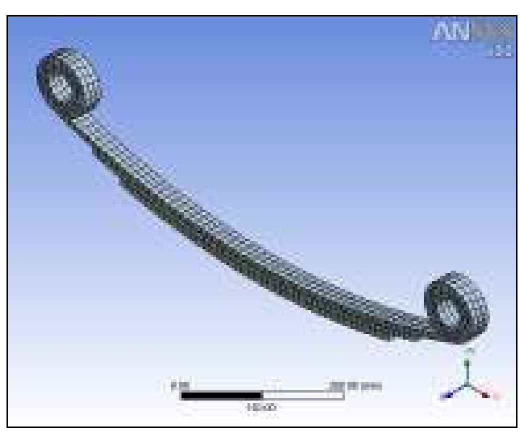


Figure (2): Mesh Geometry of Leaf Spring

6.2.2 Applying Boundary Conditions: The leaf spring is mounted on the axle of the automobile; the frame of the vehicle is connected to the ends of the leaf spring. The ends of the leaf spring are formed in the shape of an eye. The front eye of the leaf spring is coupled directly with a pin to the frame so that the eye can rotate freely about the pin but no translation is occurred. The rear eye of the spring is connected to the shackle which is a flexible link; the other end of the shackle is connected to the frame of the vehicle. The nodes of rear eye of the leaf spring are constrained in all translational degrees of freedom; Figure 3 shows the boundary conditions of the leaf spring. The load is applied along Fy direction as shown in Figure 3. Same procedure is conducted for composite leaf springs and hybrid leaf springs.

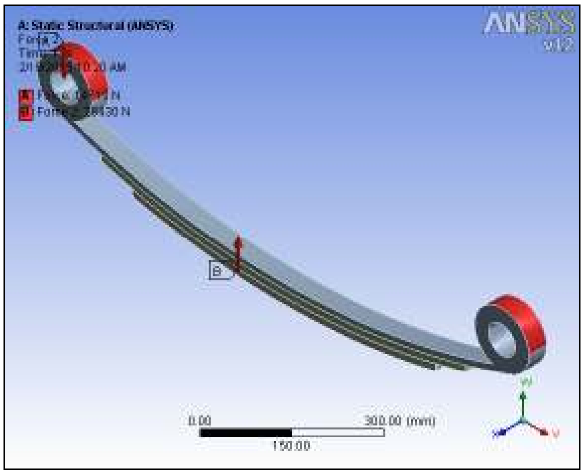


Figure (3): Boundary Conditions.

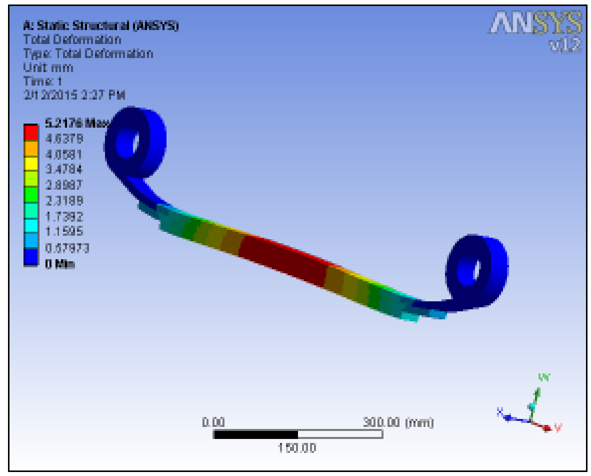


Figure (4): Total Deformation at steel (mm).

6.2.3 Static Analysis: As the finite element analysis of multi leaf spring is performed using ANSYS-14.5 workbench. The multi leaf spring for conventional steel showing deflection and Equivalent stress and Maximum Shear Stress under load is shown in Figure-4, Figue-5 and Figure-6.From Figure 6, it is obvious that maximum stress developed is at inner side of the eye sections i.e. the red colour indicates maximum stress, because the constraints applied at the interior of the eyes. Since eyes are subjected to maximum stress, care must be taken in eye design and fabrication and material selection. The material must have good ductility, resilience and toughness to avoid sudden fracture. Thus factor of safety must be increased near the eye. The same procedure is carried out for composite leaf springs, hybrid leaf springs, by changing the material properties of the corresponding materials.

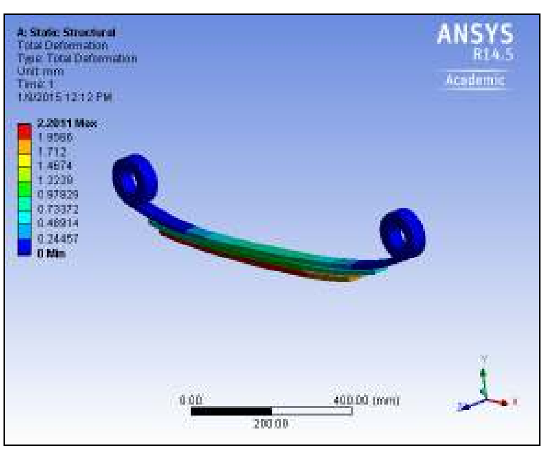


Figure (5): Total Deformation at Fiber with resin (mm).

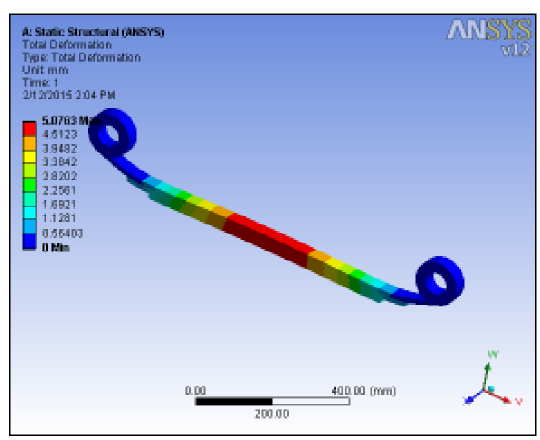


Figure (6): Total Deformation at Fiber Enhanced with nanoparticles (mm).

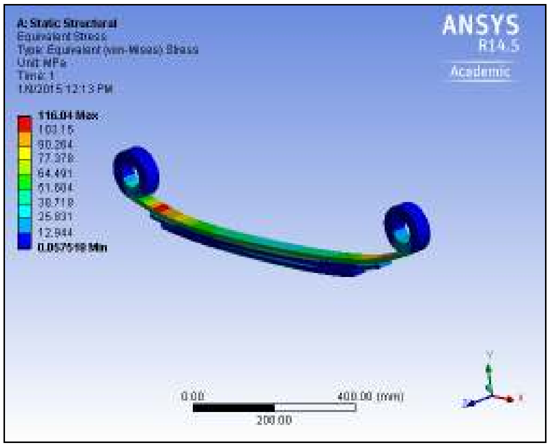


Figure (7): Equivalent stress at Steel (MPa)

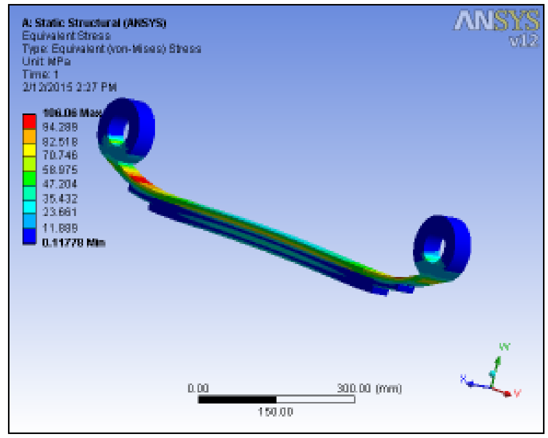


Figure (8): Equivalent stress at Fiber with resin (MPa)

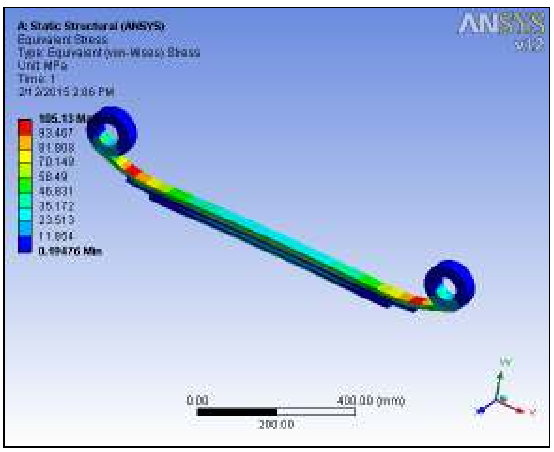


Figure (9): Equivalent stress at Fiber Enhanced with nanoparticles (MPa).

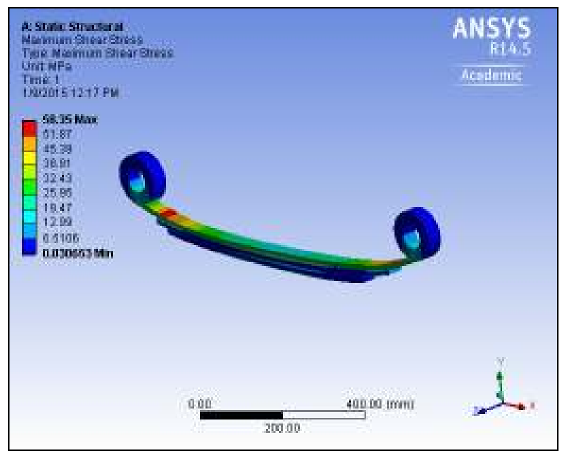


Figure (10): Maximum Shear Stress at Steel (MPa).

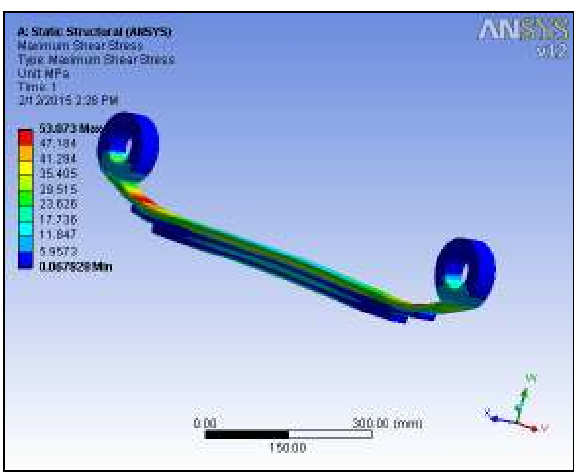


Figure (11): Maximum Shear stress at Fiber with resin (MPa).

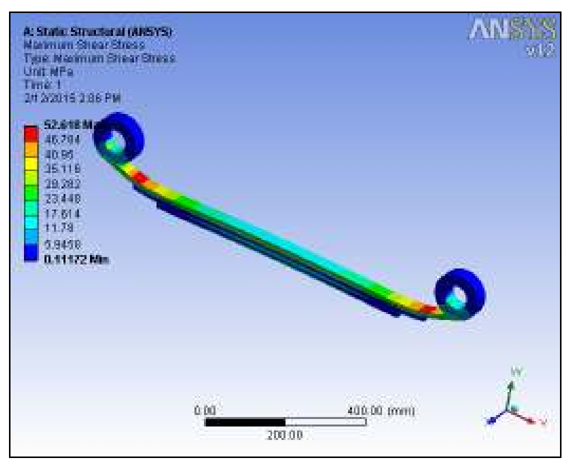


Figure (12): Maximum Shear stress at Fiber enhanced with nanoparticles (MPa).

7. Result and Discussions: Testing has been done for unidirectional E-Glass/Epoxy mono composite leaf spring only. Since the composite leaf spring is able to withstand the static load, it is concluded that there is no objection from strength point of view also, in the process of replacing the conventional leaf spring by composite leaf spring. Since, the composite spring is designed for same stiffness as that of steel leaf spring, both the springs are considered to be almost equal in vehicle stability. The matrix material is likely to chip off when it is subjected to a poor road environments (that is, if some stone hit the composite leaf spring then it may produce chipping) which may break some fibers in the lower portion of the spring. This may result in a loss of capability to share flexural stiffness. But this depends on the condition of the road. In normal road condition, this type of problem will not be there. Composite leaf springs made of polymer matrix composites have high strength retention on ageing at several environments. The steel leaf spring was replaced with a composite one. The objective was to obtain a spring with minimum weight which is capable of carrying given static external forces by constraints limiting stresses (Tsai-Wu criterion) and displacements. The weight of the leaf spring is reduced considerably about 85 % by replacing steel leaf spring with composite leaf spring. Thus, the objective of the un-sprung mass is achieved to a larger extent. The stresses in the composite leaf spring are much lower than that of the steel spring.

Table (4): Comparison Results of Steel and Composite material

		Total Deformation in (mm)			Maximum Shear Stress in (MPa)			Equivalent Stress in (MPa)		
Sl no	Loads in (kN)	Steel	Fiber with resin	Fiber Enhanced with nano particles	Steel	Fiber with resin	Fiber Enhanced with nano particles	Steel	Fiber with resin	Fiber Enhanced with nano particles
1	15.55	2.20	5.28	5.01	58.35	53.07	52.62	116.04	106.06	105.13
2	19.62	2.78	6.59	6.41	73.63	66.97	66.4	146.42	133.83	132.65
3	24.52	3.48	8.23	8.01	92.03	83.71	82.9	183.03	167.29	165.81
4	29.43	4.17	9.88	9.61	110.44	100.45	99.6	219.63	200.75	198.98

8. Conclusions: Thus the finite element modeling of the composite leaf spring was developed and it's with the static loading conditions using the orthotropic elasticity data in Ansys. It was modeled by using the pro-e software. The leaf spring system with the composite materials proves the better performance than the other conventional type steel materials. The Experimental results from testing the leaf spring under static loading conditions the stresses and deformations are calculated. The weight of the leaf spring is reduced considerably about 85% by replacing steel leaf spring with composite materials. Thus the objective of reducing the un-sprung mass is achieved to some extended and also the stresses in the composite materials are much lower than the steel leaf spring.

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