Analysis of Natural Fiber Composite Leaf Spring

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Abstract - Automobile world has an increased interest in reduction of weight by the replacement of steel by natural fiber reinforced composites. Moreover, the composite materials have more elastic strain energy storage capacity and high strength capacity and high strength to weight ratio compared to steel. Natural fibers are emerging as low cost, lightweight and apparently environmentally superior alternatives to glass fibers in composites. The aim of present work is to compare the Glass-Fiber-Reinforced - Composite (GFRC) leaf spring with a Natural-Fiber-Reinforced Composite/Jute-Fiber – Reinforced – Composite (NFRC/JFRC) leaf spring. Fabrication is carried by hand lay-up technique and tested. The present work carries analytical and simulated results comparison of both types of composite leaf springs. The testing was performed experimentally with the help of Universal Testing Machine (UTM) and by Finite Element Analysis (FEA) using ANSYS. Stresses and Deflection were verified with analytical and experimental results. Compared to the GFRC leaf spring, the NFRC Composite material spring has stresses much lower to steel and the spring weight is also reduced nearly to 60-70%.The NFRC leaf spring resulted reduction in deflection and stresses without compromising stiffness as experimentally and analytically.

Keywords: Composites, Natural Fibers, Leaf Spring, design constrains, analysis

I. INTRODUCTION

In the present scenario, to optimize the utilisation of energy, weight reduction became one of the main focuses of automobile manufacturers. Weight reduction can be achieved by the introduction of better material. 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. They carry lateral loads, brake torque, driving torque in addition to shock absorbing. Leaf springs are having an advantage that the ends of the spring may be guided along a definite path as it deflects. The use of composite materials for suspension leaf spring reduces the weight of conventional multi leaf steel leaf spring by nearly 75%.This achieves the vehicle with more fuel efficiency and improved riding qualities. For more compliant suspension system (i.e. energy storage capability), the leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential Energy is stored in spring as strain energy and then released slowly. A material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring. 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. The composite materials have more elastic strain energy storage capacity, excellent corrosion resistance, high strength to weight ratio as compared with those of steel. Conventional Multi-leaf steel springs are being replaced by mono-leaf composite springs.

Fatigue failure is the predominant mode of in-service failure of many automobile components. This is due to the fact that the automobile components are subjected to variety of fatigue loads like shocks caused due to road irregularities traced by the road wheels, the sudden loads due to the wheel traveling over the bumps etc. The leaf springs are more affected due to fatigue loads, as they are a part of the unstrung mass of the automobile. The fatigue behavior of Jute Glass Fiber Reinforced Composite materials has been studied. The fatigue strength at an arbitrary combination of frequency, stress ratio and temperature has been presented. In the present work, a multi-leaf steel spring used in passenger cars is replaced with a composite single leaf spring made of E-glass/epoxy and Jute-Glass fiber composite. The stresses for both steel leaf spring and composite leaf springs are considered as same. The primary objective is to compare their load carrying capacity, stiffness and weight savings of composite leaf spring. Finally, Natural frequencies and fatigue life of Natural Fiber reinforced composite leaf spring is also predicted using life data.

II. LITERATURE SURVEY

Many industrial visits shows that steel leaf springs are manufactured by EN45, EN45A, 60Si7, EN47, 50Cr4V2, 55SiCr7 and 50CrMoCV4 etc. These materials are widely used for production of the parabolic leaf springs and conventional multi leaf springs. Conventional (steel) leaf springs use excess of material making them considerably heavy. Automobile manufacturers and parts makers have been attempting to reduce the weight of the vehicles in recent years. Emphasis of vehicles weight reduction in 1978 justified taking a new look at composite springs. This can be improved by introducing composite materials in place of steel in the conventional spring.

Most commonly the conventional multi leaf springs are made of several steel plates of different lengths stacked together. So when they are subjected to loading, due to the deflection of consecutive leaves, we can observe the friction between the two leaves. This friction will cause the fatigue failure of steel (conventional) leaf spring. Commonly, when springs are made with number of leaves, it will carry nearly 20% of unstrung weight. For the above reasons, mono leaf composite spring will be a better option to replace the conventional steel multi leaf spring.

III. SPECIFICATION OF THE PROBLEM

Multi leaf structure creates problems such as producing squeaking sound, fretting corrosion thereby decreasing the fatigue life. The objective of the present work is to design and analyze mono leaf natural composite leaf spring. For this purpose, Glass Fiber/Epoxy & Natural fiber Glass composite leaf springs we remanufactured using hand-layup technique. Then they are experimentally tested for static load conditions and the results are compared with FEA results. The fatigue factors and natural frequencies are computed for the NFRC 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. 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

IV. DESIGN OF LEAF SPRING

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. The relationship of the specific strain energy can be expressed as

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

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

From the above equation, the material which is having low density and low Young's modulus will have high strain energy storage capacity. This purpose will be served by composites.

A. Conventional Steel multi-leaf spring

The basic requirements of a leaf spring steel is that the selected grade of steel must have sufficient hardenability for the size involved to ensure a full martensitic structure throughout the entire leaf section. In general terms higher alloy content is mandatory to ensure adequate hardenability when the thick leaf sections are used. The material used for the experimental work is 55Si2Mn90. Its chemical compositions are given below in Table 1.

Table1: Specification of Steel leaf spring

Parameters	Value
Material selected – Steel	55Si2Mn90
Tensile Strength (N/mm^2)	1962
Yield Strength (N/mm^2)	1470
Young's Modulus E (N/mm^2)	$2.1 x 10^5$
Design Stress (σ_b) (N/mm^2)	653
Total length (mm)	1010
The arc length between the axle seat and the front eye(mm)	580
Arc height at the axle seat (mm)	120
Spring rate (N/mm)	31.98
Normal static loading (N)	2943
Available space for spring width (mm)	45
Spring weight (Kg)	13.4

B. Materials selection for Composite leaf spring

A composite material is defined as a material composed of two or more constituents combined on a macroscopic scale by mechanical and chemical bonds. Typical composite materials are composed of inclusions suspended in a matrix. The constituents retain their identities in the composite. Normally the components can be physically identified and there is an interface between them.

Table2: Chemical Composition of E-Glass

Material	% Weight
Silicon oxide	54
Aluminum oxide	15
Calcium oxide	17
Magnesium oxide	4.5
Boron oxide	8
Other	1.5

Table3: Mechanical properties of E-Glass

Property	Units	Glass
Axial Modulus	Gpa	85
Transverse modulus	Gpa	85
Axial Poisson's Ratio	--	0.20
Transverse Poisson's Ratio	--	0.20
Axial shear modulus	Gpa	35.42
Axial co–efficient of thermal expansion	μm/m/ºC	5
Transverse co–efficient of thermal expansion	μm/m/ºC	5
Axial tensile strength	MPa	1550
Axial compressive strength	MPa	1550
Transverse tensile strength	MPa	1550
Transverse compressive strength	MPa	1550
Shear strength	MPa	35
Specific gravity	-	2.5

SNo	Fiber	Density(g/cm^3)	Elongation %	Tensile Strength(MPa)	Young's Modulus (GPa)
1	Cotton	1.5-1.6	7-8	287-597	5.5-12.6
2	Jute	1.3	1.5-1.8	393-773	26.5
3	Flax	1.5	2.7-3.2	345-1035	27.6
4	Hemp	1.48	1.6	690	--
5	Ramie	1.51	3.6-3.8	400-938	61.4-128
6	Sisal	1.5	2.0-2.5	5.11-635	9.4-22
7	Coir	1.2	30	175	4-6
8	Viscose	--	11.4	593	11
9	Softwood craft	1.5	--	1000	40

Table4: Mechanical properties of Natural Fibers

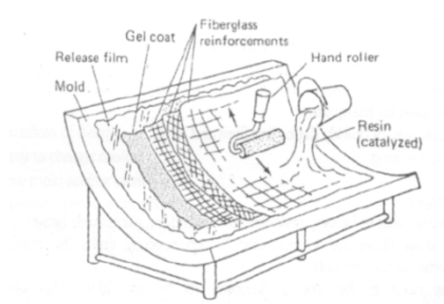
Parameter	Value
Length	1010 mm
Width	50mm
Thickness	30 mm

Table5: Dimensions of Composite Leaf spring

C. Manufacturing of Composite leaf spring

The hand layup is one of the oldest and most commonly used methods for manufacture of the composite parts. Hand layup composite are a case of continuous fiber reinforced composite. Layers of unidirectional or woven composite are combined to result in a material exhibiting desirable properties in one or more directions. Each layers oriented to achieve the maximum utilization of its properties. Layers of different material (different fiber in different directions) can be combined to further enhance the overall performance of the laminated composite material. Resins are impregnated by hand into fibers, which are in the form of woven, knitted, stitched or bonded fabrics. This is usually accomplished by rollers or brushes, with an increase use of nip–roller type impregnators for forcing resin into fabrics by means of rotating rollers and a bath of resin. Laminates are left to cure under standard atmospheric conditions.

Fig1: Typical Hand Lay – Up Technique



D. Fabrication Procedure

A plywood mould was prepared with required dimensions of leaf spring. Wax polish (Manson) was applied with the help of cloth on mould for better surface finish & for easy removal of leaf spring after curing. Number of layers of E-glass, Jute and epoxy are laminated simultaneously for required thickness of leaf spring. Then it is cured for 24 hours before removal.

Table6: Dimensions of Mould

Parameters	Value (mm)
Arc length	1160
Length	1010
Width	45
Arc height at the axle	130

Fig2: Prepared Jute-Eglass-Epoxy composite leaf spring

V. EXPERIMENTAL TESTING

After fabrication of both (E-glass/epoxy & Natural fiber E-glass epoxy) leaf springs are experimentally tested on UTM machine at load intervals of 5kgs. The experimental data of deflection against load was recorded.

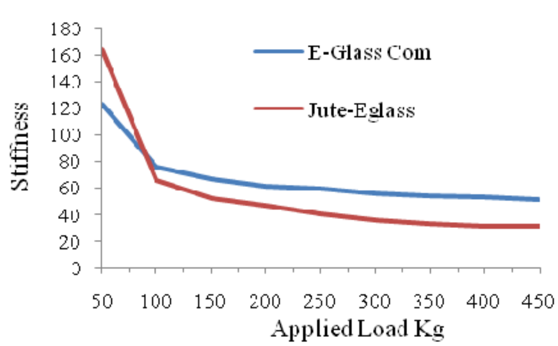
Table7: Comparison of deflection of Leaf springs

SNO	Applied loads	Deflection of Composite leaf	
		E glass	jute glass epoxy
1	50	4	3
2	100	13	15
3	150	22	28
4	200	32	42
5	250	41	60
6	300	53	82
7	350	64	103
8	400	74	125/520 Break

Table8: Comparison of stiffness of Leaf springs

SNo	Applied load Kg	Stiffness of Composite leaf	
		E-glass	jute Glass
1	50	123	164
2	100	75	65
3	150	67	53
4	200	61	47
5	250	60	41
6	300	56	36
7	350	54	33
8	400	53	31

Graph1: Comparison of stiffness of Leaf springs



VI. Finite Element Analysis

To design composite leaf spring, static stress analysis was performed using Finite element methods. Analysis carried out for composite leaf spring for Glass/Epoxy, and Jute glass Epoxy composite materials and the results were compared. 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.

Fig3: Build Model

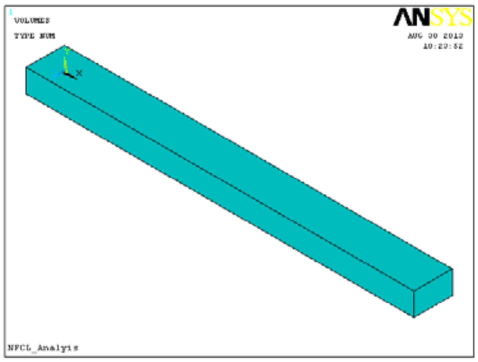
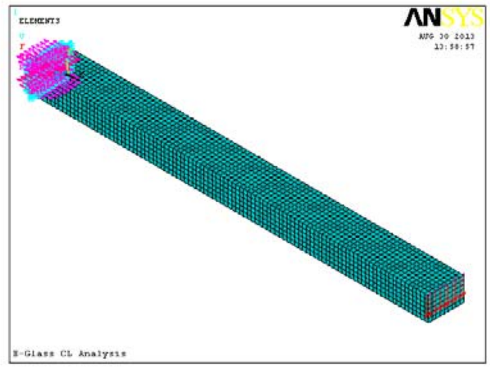


Fig4: Meshed model and applied boundary conditions



A. Results for E-glass / Epoxy composite

Fig5: Displacement in X-direction

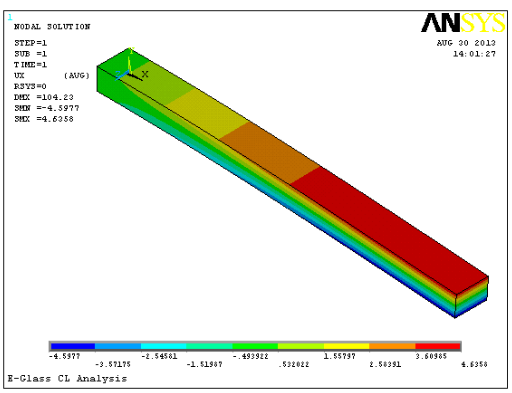
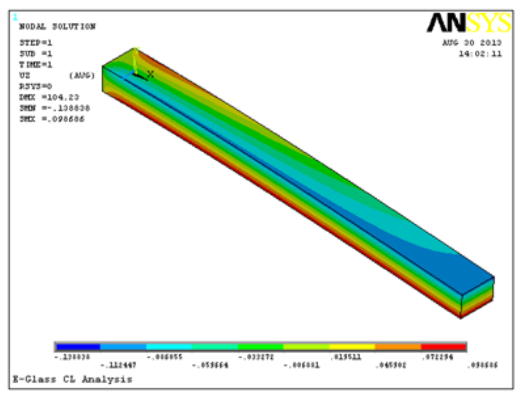
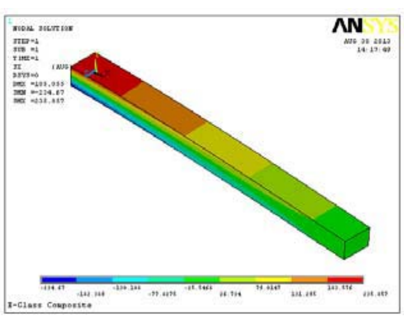


Fig6: Stress distribution in X-direction





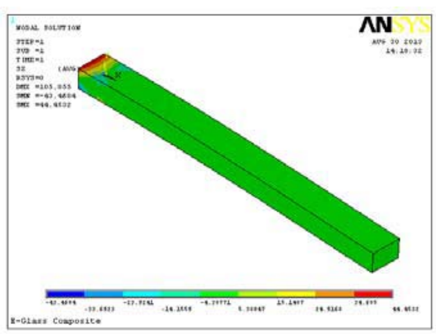


Fig7: Displacement in Z-direction

Fig8: Stress distribution in Z-direction

B. Results for Jute-E-glass / Epoxy composite

Fig9: Deflection in x-direction

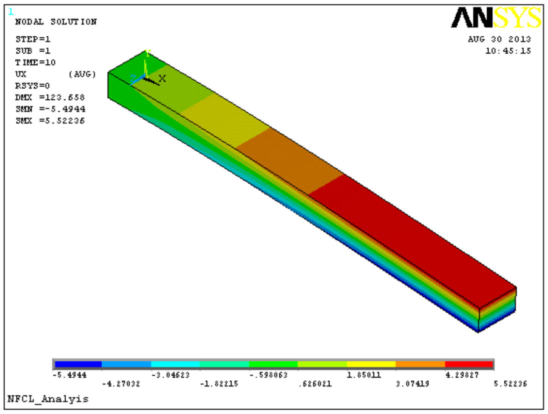


Fig10: Stress distribution in x-direction

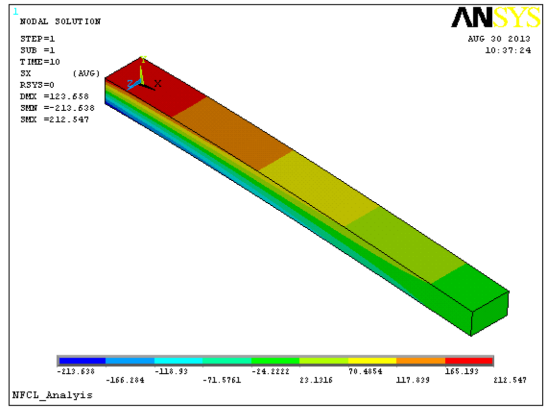
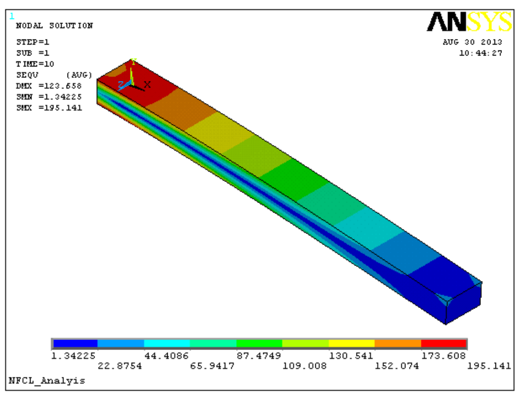


Fig11: VonMises Stress distribution



Minimum Values of stress in N/mm² (Compressive)

Node	126	254	257	252	157	2
Value	-213.64	-41.409	-44.527	-23.069	-7.265	-38.564

Maximum Values of stress in N/mm² (Tensile)

Node	1	10	367	4	6	128
Value	212.55	39.578	42.630	24.395	7.1813	38.799

Maximum deflection in Y-direction:

NODE	6
VALUE	-123.53mm

C. Modal Analysis

Modal analysis is used to determine a structure's vibration characteristics — natural frequencies and mode shapes. It is the most fundamental of all dynamic analysis types and is generally the starting point for other, more detailed dynamic analyses.

Different Mode shapes:

Fig12: Mode shape1

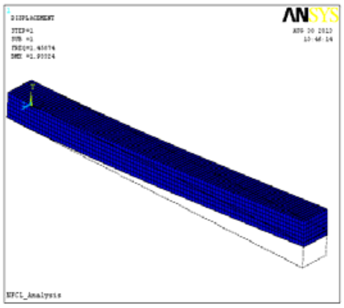


Fig13: Mode shape2

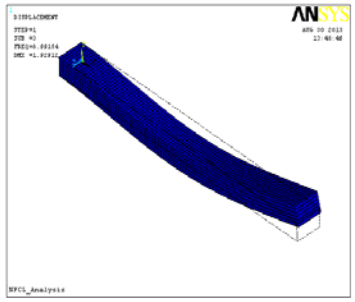


Fig14: Mode shape3

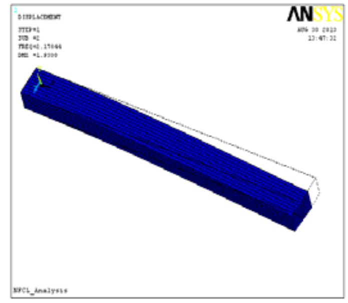


Fig15: Mode shape4

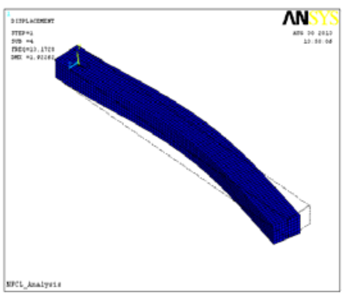


Fig14: Mode shape5

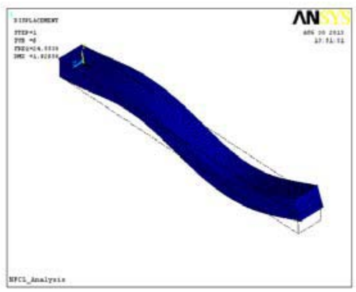
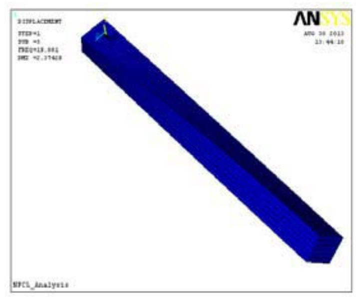


Fig15: Mode shape6



Material	Natural frequency Hz					
	Mode1	Mode2	Mode3	Mode4	Mode5	Mode6
E Glass /Epoxy	1.28	1.92	7.94	12.59	18.52	23.60
Jute Eglass Epoxy	1.46	2.18	8.99	13.17	19.88	24.55

Table9: Natural Frequencies of Composite leaf spring

D. Fatigue Analysis

It is estimated that 50-90% of structural failure is due to fatigue, thus there is a need for quality fatigue design tools. The focus of fatigue in ANSYS is to provide useful information to the design engineer when fatigue failure may be a concern. Fatigue results can have a convergence attached. A stress-life approach has been adopted for conducting a fatigue analysis.

Factors affecting fatigue –life

- Cyclic stress state
- Geometry
- Surface quality
- Material Type
- Residual stresses
- Direction of loading
- Grain size
- Temperature

Resulting Stresses due to fatigue at various nodes

Table10: Stress at various nodes and no of cycles

Node	1	126	364	423
No of Cycles	10^6	10^6	10^6	10^6
Stress N/mm²	242.2	181.1	15.7	125.74

VII. Results and Discussion

A steel leaf spring is replaced with two types of composite mono leaf springs. They are experimentally tested and the results are verified with FEA. Main consideration was given to the jute E-glass epoxy composite leaf spring. The objective was to obtain a natural fiber composite leaf spring that is capable of carrying given static external forces by constraints limiting stresses and displacements.

Table11: Comparison between composite leaf springs

	E glass/ epoxy	Jute-E glass epoxy
Deflection mm	114.23	123.68
Max stress (analytical)	220.18	220.18
Max stress (FEA)N/mm²	212.55	235.86
Weight in Kg	3.59	2.59

The results showed that the maximum stress and displacements are within the limit (Tensile stress 850N/mm², compressive stress 450N/mm², deflection 130mm) for both composite materials. Compared to the weight of steel leaf spring (9.35Kgs), 62% and 72% weight reduction is possible for E-glass epoxy and natural fiber mono leaf composite springs respectively without effecting the load carrying capacity. Natural fiber composite is having equal strengths as e-glass epoxy with further weight reduction by 28%. The natural frequency of composite leaf spring is higher than enough from the road frequency to avoid the resonance.

VIII. Conclusions

Experimental results from testing the leaf spring under static loading condition the stresses and deflections are calculated. These results are compared with FEA. Mono composite leaf springs for the vehicular suspension system was designed using E-Glass/Epoxy, Natural fiber 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.GFRC and Jute glass epoxy composite are considered to be almost equal in vehicle stability and both are manufactured with same dimensions. The major disadvantage of GFRC and Jute Glass Epoxy composite leaf spring are chipping resistance.

The objective was to fabricate and analyze the springs with minimum weight which is capable of carrying given static external forces by constraints limiting stresses and displacement. The weight of the leaf spring is reduced considerably about 75% by replacing steel and GFRP and Jute-E-Glass-Epoxy composite leaf spring thus, the objective of reducing the un-sprung mass is achieved to a larger extent.

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