Static Analysis of Composite Mono Leaf Spring For LCV (TATA ACE) - Design, Manufacturing and Testing

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Abstract- **For the light commercial vehicle (TATA ACE) replacement of conventional steel leaf spring by composite Eglass/Epoxy material has many advantages because of higher stiffness and strength of composite material. It also gives high strength to weight ratio. A mono composite leaf with variable thickness and width for constant cross sectional area of unidirectional fiber reinforced plastic (FRP) with similar mechanical and geometrical properties to the multi leaf spring was designed, fabricated and tested. This work deals with replacement of conventional steel leaf spring (TATA ACE) with composite mono leaf spring using E-glass/Epoxy. The design parameter were selected and analyzed with the objective of minimizing the weight of composite leaf spring compared to steel leaf spring. The leaf spring can be modeled in Pro-E and and analysis was done using ANSYS software. The finite element results of stresses and deflection were verified with analytical and experimental results. A typical leaf spring configuration of TATA ACE light commercial vehicle chosen for study.**

Keywords: **Leaf spring; composite; Modeling; Static Analysis; FEA**

1. INTRODUCTION

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturers in the present scenario. 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 as it accounts for 10% - 20% of the unstrung weight. 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. Since, the composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel, multi-leaf steel springs are being replaced by mono-leaf composite springs. .

The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring

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deflection so that the potential Energy is stored in spring as strain energy and then released slowly[1]. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. 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. Fortunately, composites have these characteristics

In the present work, a multi-leaf steel spring used in TATA ACE is replaced with a composite mono leaf spring made of glass/epoxy composites. The some dimensions for both steel leaf spring and composite leaf springs are considered to be the same. The primary objective is to compare their load carrying capacity, stiffness and weight savings of composite leaf spring. Finally, fatigue life of steel and composite leaf spring is also predicted using life data[2].

In this analysis the conventional steel leaf spring is tested for static load condition and results are compared with a virtual model of composite material leaf spring. Leaf spring is modeled in Pro-E CREO Element E5 software and it is imported and simulated in ANSYS 14.0 for better understanding. Results of Composite Leaf Spring are compared on the basis of analysis reports produced by ANSYS software. The material used for conventional steel leaf spring is 55Si2Mn90 and for composite leaf spring E-Glass/Epoxy material is used.

2. MATERIAL FOR LEAF SPRING

High damping capacity of composite materials can be beneficial in many automotive applications in which noise, vibration, and hardness is a critical issue for passenger comfort.

Selection of the suitable material is a key factor because of overall properties for the composite spring depends upon the material used for manufacturing of the spring. Fiber Reinforced Composite (FRP) are composite materials consisting of fibers of high strength and modulus embedded in or bonded to a resins with distinct interfaces between them. In this form, both fibers and resins retain their physical and chemical identities yet they produce combination of properties that cannot be achieved with either of the constituents acting alone. In general, fiber are the principal load carrying members, while the surrounding resins keeps them in desired location and orientation.

The material for conventional steel leaf spring is 55 Si 2 M N90 . material selected for mono composite spring is E-glass/Epoxy. i.e.Eglass-60%, Epoxy resin-40%. A mono-leaf E-glass – epoxy has been used to replace a three-leaf steel spring with nearly an 80 % weight savings.

3. DESIGN OF MONO LEAF SPRING

In this design both thickness and width are varied through out the leaf spring such that the cross-section area remains constant along the length of the leaf spring. The constant cross-section design method is selected due to the following reasons: Due to its capability for mass production of continuous reinforcement of fibers. Since the cross-section area is constant through out the leaf spring, same quantity of reinforcement fiber and resin can be fed continuously during manufacture. The joint consists of a steel eye that can be bolted or pinned to the spring. Because of drilling, a region of stress concentration will exist around the holes in this type of attachment. Simplicity and low cost are the advantageous of this attachment.

Table no.- 1 Actual Parameter of conventional steel leaf spring

Sr.No.	Parameter	Value
1	Material selected – Steel	55Si2Mn90
2	Tensile strength (N/mm2)	1962
3	Yield strength (N/mm2)	1470
4	Young's modulus *E* (N/mm2)	$2.1 \cdot 10^5$
6	Total length (mm)	850

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7	spring width (mm)	60
8	Spring weight (kg)	22
9	No. of full length leave	3
10	Thickness of leaf (mm)	8
11	Maximum Load given on spring (N)	3850

Table no.-2 DESIGN PARAMETER FOR COMPOSITE MONO LEAF SPRING

Sr.no.	Properties	value
1.	Tensile modulus along X-direction E_X , Mpa	34000
2.	Tensile modulus along Y-direction E_Y , Mpa	6530
3.	Tensile modulus along Z-direction E_Z , Mpa	6530
4.	Tensile strength of the material, MPa	900
5.	Compressive strength of the material, MPa	450
6.	Shear modulus along XY-direction (Gxy), MPa	2433
7.	Shear modulus along YZ-direction (Gyz), MPa	1698
8.	Shear modulus along ZX-direction (Gzx), MPa	2433
9.	Poisson ratio along XY-direction (NUxy)	0.217
10.	Poisson ratio along YZ-direction (NUyz)	0.366
11.	Poisson ratio along ZX-direction (NUzx)	0.217
12.	Mass density of the material (ρ), kg/mm3	$2.6*10^{-6}$
13.	Flexural modulus of the material, MPa	40000
14.	Flexural strength of the material, MPa	1200

3.1 Specific Design Data

Here Weight and initial measurements of four wheeler “TATA ACE” light commercial vehicle are taken.

Weight of vehicle= 500 kg

Maximum load carrying capacity= 1000 kg

Total weight= 500 + 1000 = 1500 kg;

Taking factor of safety (FS) = 3,

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

There for; Total Weight (W’) = 1500*10*2 = 45000 N

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

F = 45000/4 = 11250 N

For E-glass / Epoxy : maximum stress (σ_{max}) = 500 N/mm^2 , maximum deflection (δ_{max}) = 100 mm,

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Since analysing half of the leaf spring is enough, half of the applied force would have been taken. But here we took as it is to account over loadings of the vehicle and flexures of the leaf spring.

Hence, L/2 = 415 mm, F = 11250 N, t = ? and b = ?

Calculating for 't' and 'b' dimensions which are capable of withstanding the loading behaviour of the composite (E-glass/ Epoxy) leaf spring is the result of this design.

From equations of strength of materials we have;

$$\sigma_{max} = \frac{6.F.L}{b.t2} \quad \ldots\ldots\ldots\ldots(1)$$

$$\delta_{max} = \frac{6.F.L3}{E.b.t} \quad \ldots\ldots\ldots\ldots(2)$$

Solving equations 1 and 2 simultaneously for 't' (thickness of the leaf spring);

$$t = \frac{\sigma max \quad (L/2)2}{E \quad \delta max} \quad \ldots\ldots\ldots(3)$$

$$b = \frac{6.F.L/2}{\sigma max.t2} \quad \ldots\ldots\ldots\ldots(4)$$

by putting the values we can get the both ' t ' and ' b '

for calculating the bending stress

$$\sigma_b = M*y/I$$

since $y = t/2$, $I = bt^3/12$

Taking the other dimension same of steel leaf spring.

Thickness at end of leaf = 8 mm

Eye end inner diameter = 21 mm

Width at the end of leaf = 98 mm

Bolt Size = M8 Pitch 1.25

Fatigue life of mono composite leaf spring :

$$N = \{ B (1- r) \}^{1/c}$$

Where N is number of cycles, B = 10.33, C = 0.14012

Calculated $N = 534.32 * 10^2$ cycles

4. MANUFACTURING PROCESS

We used a hand-lay-up method to produce the prototype of a single composite leaf spring. The constant cross section design is used which accommodate continuous reinforcement of fibers and quite suitable for hand lay-up technique.

The uniform cross section design for spring was selected due to its capability of mass production and also it is quite suitable for producing using hand lay-up technique. In this case , the hand lay-up process was employed. Templates (mould die) required were made from wood and plywood according to desired profile. Initially the glass fibers were cut to the desired lengths, so that they can be deposited on the mould die layer by layer during fabrication. After which a releasing agent (gel/wax) was applied uniformly to the mould to get a good surface finish. A glass fiber is then placed over the mould followed by the uniform application of epoxy resin (composition: glass 60% and epoxy 40%) over the glass fiber. Another glass fiber layer is layered and epoxy resin was applied and a roller was used to remove all the trapped air. This process continued till the required dimensions were obtained. Fiber distortion should be avoided by taking proper care during individual lay-up of the layers. The duration of the process is about 30 min and the mould is allowed to cure about 4-5 days at room temperature. Mono composite leaf spring without eye ends is fabricated by using the above technique. Composition of E-glass: Silica-70-74%; Sodium oxide-12-16%; Calcium oxide-1-3%; Magnesium oxide-1-3%; Aluminium oxide-1-3%.

Fig. 1 Mould set up of composite mono leaf spring

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Fig. 2 Final trimmed composite mono leaf spring

Fig. 3 Actual composite mono leaf

5. FINITE ELEMENT ANALYSIS

To design the composite spring , a stress analysis was performed using the finite element method done using ANSYS software . modeling was done on software Pro-E creo E5. Also, analysis carried out for composite leaf spring with end joints for E-glass / Epoxy. The maximum shear stresses along the adhesive layer were measured and represent the FEA results of composite mono leaf spring. The above fig.3 and fig.4 shows the deflection and stress measured on the composite mono leaf spring by ANSYS 14.0

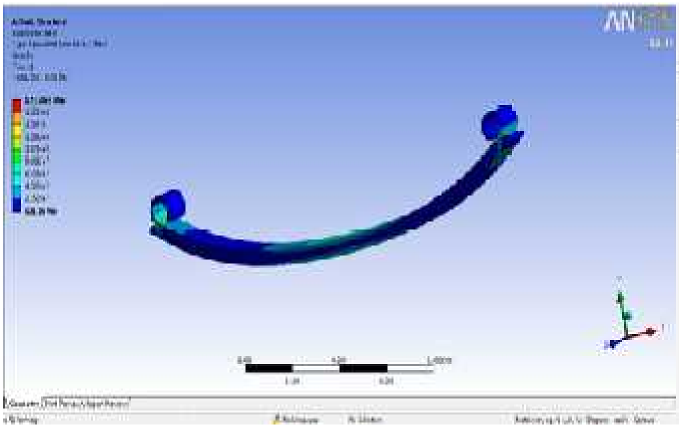

Fig. 6 stresses on steel leaf spring

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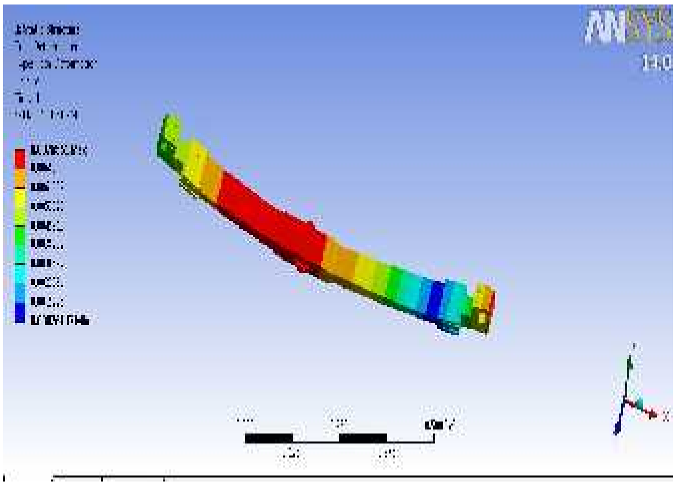

Fig. 4 Deflection of composite mono leaf spring

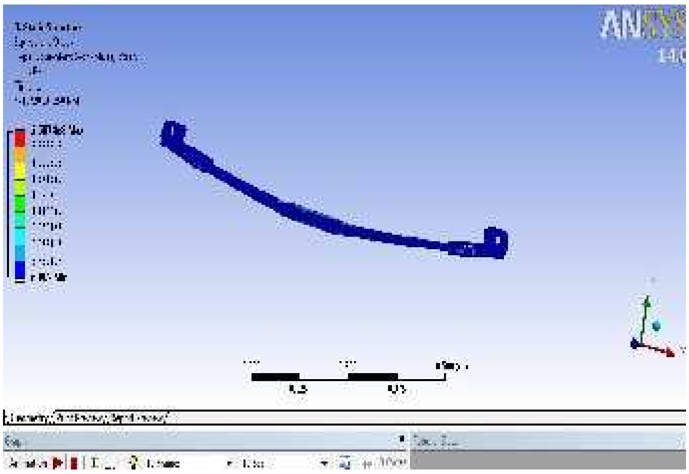

Fig. 5 stresses of on composite mono leaf sprin

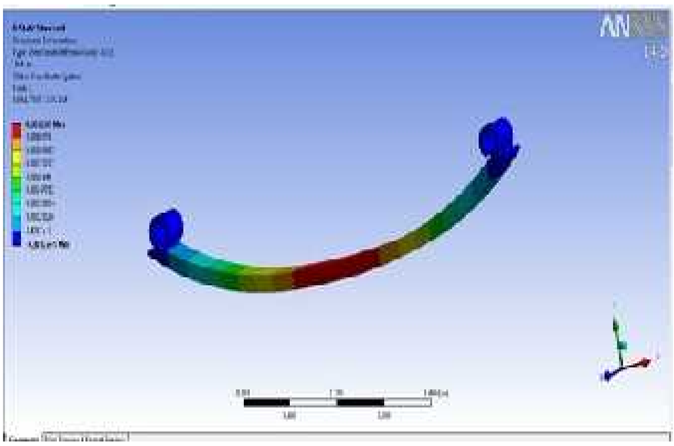

Fig. 7 displacement of steel leaf spring

6. RESULTS AND DISCUSSION

When we compare the values, tabulated in Table below, both the experimental and analysis stress values are much less than that of strength properties of the material. Therefore the maximum stress failure criterion is satisfied, hence safe design of the product. The fatigue life of the designed single E-glass/ Epoxy composite leaf spring is predicted and obtained as N= $534.32*10^2$ cycles. This shows the acceptable life or good resistance of the material to failure

Table no. – 3 **RESULTS**

MATERIAL	STATIC LOAD (N)	MAXIMUM STRESS (MPA)	MAXIMUM STRESS FEA (MPA)	MAXIMUM DISP. (MM)	MAXIMUM DISP. FEA (MM)	STIFNESS N/MM	WEIGHT Kg
Steel	3000	523	478.67	42.40	62.43	70.74	20.35

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E-glass/Epoxy	3000	500	675.24	13.21	26.86	227.10	9.2

7. CONCLUSION

i. 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.

ii. 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.

iii. 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.

iv. 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.

v. 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 %.

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