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Static Analysis and Fatigue Life prediction of Composite Leaf Spring for a Light Commercial Vehicle (TATA ACE)

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Abstract— ***In this research work an attempt has been made to check the suitability of composite materials like E-Glass/Epoxy, Graphite/Epoxy, Boron/Aluminum, Carbon/Epoxy and Kevlar/Epoxy for light commercial vehicle leaf spring. First the static analysis is carried out for steel and different composite leaf spring using FE solver ANSYS V10. The obtained results are compared with theoretical values and observed that they have good agreement with each other. The fatigue life of various composite leaf springs is calculated using Hwang and Han relation. From the results it can be concluded that Boron/Aluminum and Graphite/Epoxy are best suitable composite material for leaf spring.***

Keywords—leaf spring, composite, Conventional steel leaf spring

I. Introduction

Composite materials consist of two or more physically dissimilar and instinctively separable components called reinforcement and matrix. These two components can be mixed in a restricted way to achieve optimum properties, which are superior to the properties of each individual component. Composite materials have been widely used in automobile industry because of its high strength and modulus to weight ratio, low cost and flexibility in material and structure design. 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. This helps in achieving the vehicle with improved riding qualities. Since the strain energy in the spring is inversely proportional to density and young's modulus of the material, it is always suggested that the material for leaf spring must have low density and modulus of elasticity. Many researches have been carried out in the direction to replace conventional steel leaf spring by composites. Shiva Shankar and Vijayarangan [5] (2006) have designed, fabricated (hand- lay up technique) and tested of a single leaf with variable thickness and width for constant cross sectional area of unidirectional glass fiber reinforced plastic (GFRP). Senthil Kumar and Vijayarangan [6] (2007) have carried out design and experimental fatigue analysis of composite multi leaf spring using data analysis. Patunkar and Dolas [8] (2011) have modeling and analyzed composite mono leaf spring (GFRP). Shishay [1] (2012) has designed and simulated a single E-glass/Epoxy leaf spring for light weight three wheeler vehicles. Ranjeet et al. [2] (2012) have carried out stress analysis of mono composite leaf spring under the dynamic load conditions and natural frequencies. Vijaya Lakshmi and Satyanarayana [10] (2012) have studied the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. Anuraag and VenkataSivaram [7] (2012) have analyzed the leaf springs to predict the behavior under static, dynamic & shock. Sailaja et al. [3] (2013) have modeled and analyzed a master leaf spring with respect to weight and strength. Digambar et al. [4] (2013) have carried out modeling of a master leaf spring using CATIA V5R17 and static analysis of two conventional steel leaf springs made of SUP 10 & EN 45. Ghodake and Patil [9] (2013) have presented the design and analyzed composite leaf spring made of glass fibre reinforced polymer.

II. Leaf Spring Specifications of TATA ACE

In this research work TATA ACE composite leaf spring with constant width and constant thickness with uniform cross section is considered as shown in Figure1. The design parameters such as spring length, spring thickness, spring width and camber are kept to be the same in both steel and composite leaf springs. The specifications of leaf spring are given in table 1. The material properties of 55Si2Mn90 steel are shown in table 2.

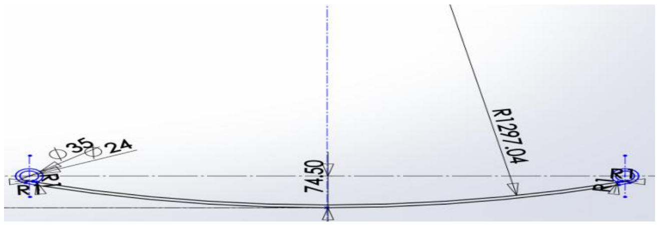

Figure 1 2D drawing of TATA ACE Master Leaf Spring

Table 1 Leaf Spring Specifications of TATA ACE

Total Length (L)	930 mm
Length of leaf spring from Eye to Eye	754 mm
Thickness (t)	8 mm
Width (b)	60 mm
Load (W) given on leaf spring	1000 N

Table 2 Material Properties of 55Si2Mn90 Steel [5]

1	Ultimate tensile strength Su (Mpa)	1962
2	Yield tensile strength Su (Mpa)	1470
3	Modulus of elasticity E (Gpa)	210
4	Poisson ratio	0.3

III. Design Requirements of Composite Leaf Spring

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The objective for the optimum design of the composite leaf spring is the minimization of weight. This objective function is constrained by the functional requirements of the leaf spring, which is static load carrying capability of the leaf spring: $\sigma d \geq \sigma max$. Thus together with constraints from the functional requirements, the objective function is optimized by varying the design variables so that functionally sound, minimum weight leaf spring is realized. Material properties of different composites are given in the table 3.

Table 3 Material Properties of different Composite Materials [11]

Material Properties	E-Glass/ Epoxy	Graphite/ Epoxy	Boron/ Alumi num	Carbon/ Epoxy	Kevlar/ Epoxy
E_{11} (MPa)	34000	142600	215000	142000	80000
E_{22} (MPa)	6530	9600	14410	9810	5500
G_{12} (MPa)	2433	600	5720	657	220
G_{22} (MPa)	1698	310	4590	377	180
V_{12}	0.217	0.25	0.19	0.3	0.34
V_{23}	0.366	0.35	0.29	0.34	0.65

IV. Theoretical Analysis of Steel and Composite Leaf Spring

For the theoretical formulation of composite leaf spring, it is assumed as curved beam shown in Figure 2, because the leaf spring is fixed with the axle at its centre. The curved beam is subjected to a bending moment and is as shown in Figure 3.

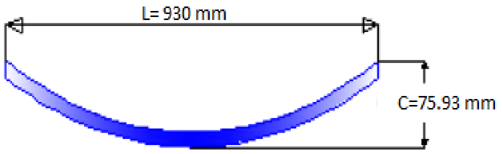

Figure 2 Leaf Spring as a Curved Beam

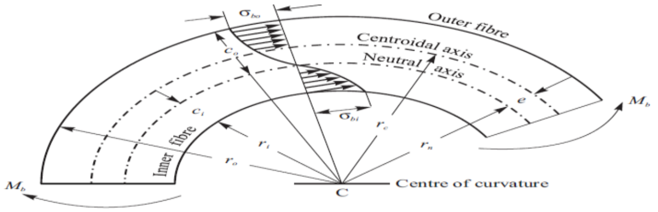

Figure 3 Curved Beam Subjected to a Bending Moment Mb

The neutral axis is shifted towards the centre of curvature by a distance called eccentricity 'e'. The value 'e' should be computed very accurately since a small variation in the value of 'e' causes a large variation in the values of stress.

i.e., $e = r_c - r_n$

c_i = Distance between neutral axis and inner fibre = $r_n - r_i$

c_o = Distance between outer fibre and neutral axis = $r_o - r_n$

From fundamental equation of bending,

$$\frac{M_b}{I} = \frac{\sigma_b}{y} \quad \text{……... (1)}$$

i.e., bending (maximum allowable stress) stress (Mpa) is given by,

$$\sigma_b = \frac{M_b}{I} y \quad \text{......... (2)}$$

Where,

$$I = \left(\frac{bt^3}{12}\right) \quad \text{…….. (3)}$$

I = moment of area about neutral axis. M_b = WL/4 = the moment about the neutral axis.
y = t/2 = the perpendicular distance to the neutral axis.

The maximum deflection (mm) of a simply supported beam loaded in the centre is given by,

$$\delta = \left(\frac{WL^3}{48\,EI}\right) \quad \text{………. (4)}$$

Where, E= young's modulus of material (MPa)

Maximum stiffness (N/mm) is given by,

$$K = \frac{Load}{Deflection} \quad \text{………. (5)}$$

For prediction of fatigue life, Senthil and Vijayarangan [8] has adopted the analysis model of Hwang and Han and it is proved that the analytical formula predicts the fatigue life of component with E-Glass/Epoxy composite material, using Hwang and Han relation;

$$N = \{B(1-r)\}^{1/c} \quad \text{……. (6)}$$

Where, N is the number of cycles to failure, B = 10.33, C = 0.14012 and r = (maximum stress/ultimate tensile stress) = applied stress level.

V. Finite Element Analysis of Steel and Composite Leaf Spring

The static analysis is carried out using ANSYS V10 to find out maximum deflection and von mises stress under static load applied at the centre of the spring. The obtained displacement contour and von mises stress distribution for Steel, E-Glass/Epoxy, Graphite/Epoxy, Boron/Aluminum, Carbon/Epoxy and Kevlar/Epoxy leaf springs are as shown in Figures 4 to 15 respectively.

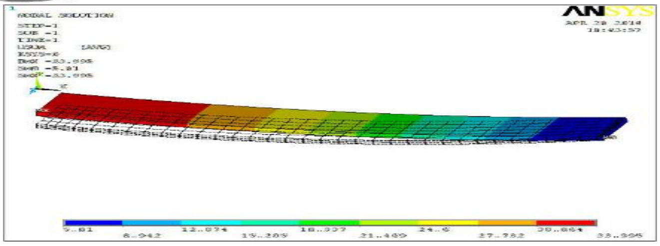

Figure 4 Displacement Contour for Steel Leaf Spring

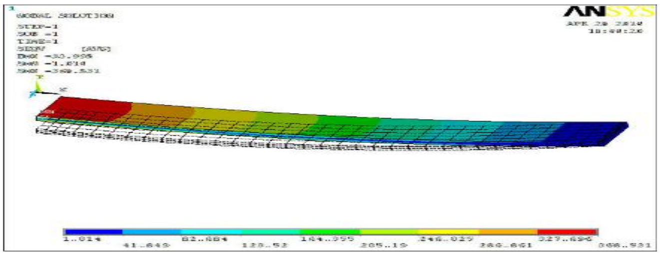

Figure 5 Displacement Contour for E-Glass/Epoxy Leaf Spring

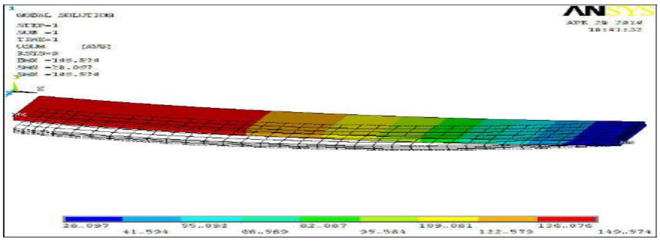

Figure 6 Displacement Contour for Graphite/Epoxy Leaf Spring

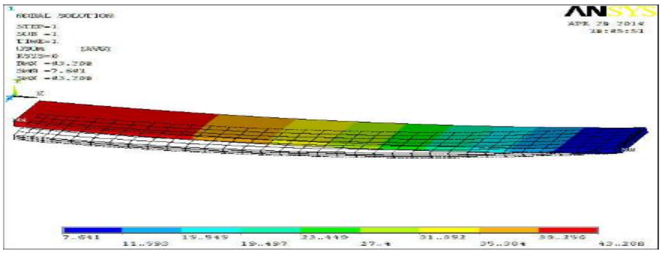

Figure 7 Displacement Contour for Boron/Aluminum Leaf Spring

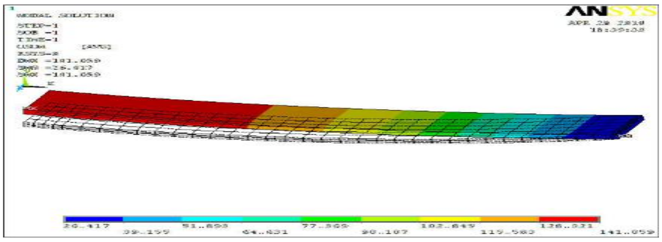

Figure 8 Displacement Contour for Carbon/Epoxy Leaf Spring

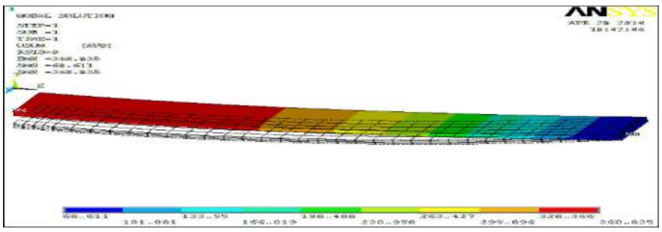

Figure 9 Displacement Contour for Kevlar/Epoxy Leaf Spring

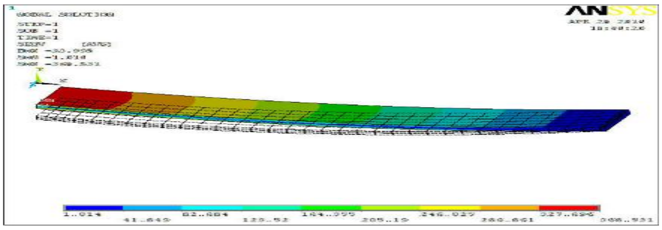

Figure 10 Von Mises Stress Distribution for Steel Leaf Spring

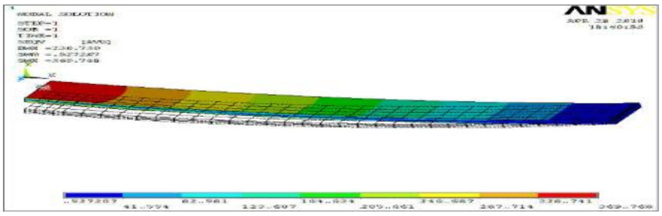

Figure 11 Von Mises Stress Distribution for E-Glass/Epoxy Leaf Spring

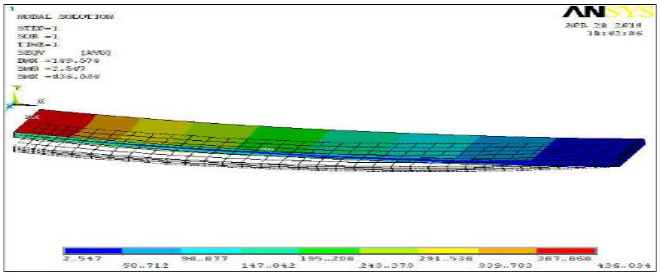

Figure 12 Von Mises Stress Distribution for Graphite/Epoxy Leaf Spring

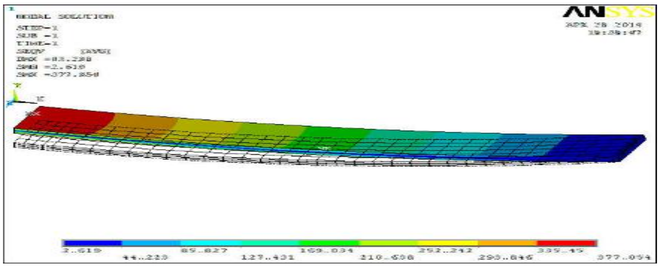

Figure 13 Von Mises Stress Distribution for Boron/Aluminum Leaf Spring

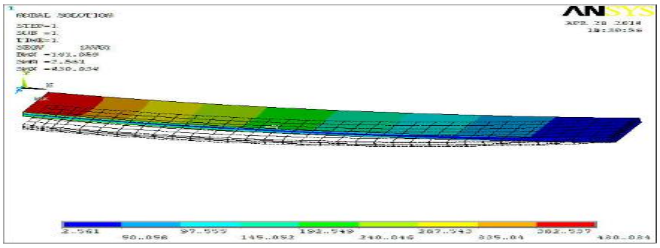

Figure 14 Von Mises Stress Distribution for Carbon/Epoxy Leaf Spring

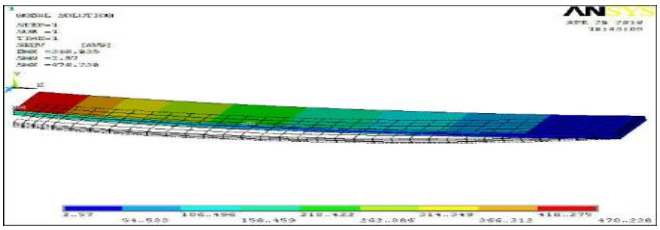

Figure 15 Von Mises Stress Distribution for Kevlar/Epoxy Leaf Spring

VI. Result and Discussion

A. Static Analysis of Steel and Composite Leaf Springs

Obtained deflection and von mises stress are compared with theoretical results and tabulated in table 4. FEA solver results shows that the deflection and von mises stress is more in E-Glass/Epoxy, Graphite/Epoxy, Carbon/Epoxy and Kevlar/Epoxy than conventional steel leaf spring. The steel and Boron/Aluminum have minimum deflection and von mises stress because they posses high stiffness compared to other composite materials. And also it is observed that the Boron/Aluminum is capable of carrying a given static external forces by constraints limiting stress and displacements.

Table 4 Comparison results of Deflection, Stress and Stiffness for different material Leaf Springs

Material	Static load (N)	Maximum deflection (mm)		Maximum von mises stress (MPa)		Stiffness (N/mm)
		FEA	Theoretical	FEA	Theoretical	
Steel	1000	33.995	31.1708	368.531	363.281	29.416
E-Glass/Epoxy	1000	230.739	192.526	369.768	363.281	4.334
Graphite/Epoxy	1000	149.574	45.904	436.034	363.281	6.686
Boron/Aluminum	1000	43.208	30.446	377.054	363.281	23.144
Carbon/Epoxy	1000	141.059	46.098	430.034	363.281	7.089
Kevlar/Epoxy	1000	360.835	81.823	470.238	363.281	2.771

B. Fatigue Life of Composite Leaf Spring

The fatigue life of various composite leaf springs at different stress levels is tabulated in the table 5 and it is observed that Graphite/Epoxy and Boron/Aluminum are withstanding more than 10, 00,000 cycles at stress levels of 0.215 and 0.226 and also the fatigue life is more as compared to that of conventional steel leaf spring.

Table 5 Fatigue life at different stress levels of various Composite Leaf Springs

Composite Material	Maximum Induced stress (MPa)	Ultimate Tensile stress (MPa)	Applied stress level	Number of cycles to failure
E-Glass/Epoxy	369.768	900	0.411	357944
Graphite/Epoxy	436.033	2031	0.215	2737319
Boron/Aluminum	377.054	1672	0.226	2476977
Carbon/Epoxy	430.033	600	0.717	1993
Kevlar/Epoxy	470.034	1300	0.362	630374

VII. Conclusion

In this research work, static analysis for various leaf springs is carried out using ANSYS 10 and the fatigue life of various composite leaf springs is calculated. From the obtained results it can be concluded that.

1. A comparative study has been made between different composite materials and with steel in respect of stiffness, deflection and stress.
2. Obtained FEA results have good agreement with theoretical results.
3. Boron/Aluminum has minimum deflection and stress, and posses high stiffness as compared to other composites.
4. Graphite/Epoxy and Boron/Aluminum withstand more than 10,00,000 cycles at stress levels of 0.215 and 0.226.

Hence composite leaf spring has good performance characteristics as compared to conventional steel spring with similar design specifications.

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