Design and Analysis of Composite Leaf Spring by Using FEA and ANSYS

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Abstract: Increasing competition and innovation in automobile sector tends to modify the existing products by new and advanced material products. A suspension system of vehicle is also an area where these innovations are carried out regularly. Leaf springs are one of the oldest suspension components that are being still used widely in automobiles. Weight reduction is also given due importance by automobile manufacturers. The automobile industry has shown increased interest in the use of composite leaf spring in the place of conventional steel leaf spring due to its high strength to weight ratio. The introduction of composite materials has made it possible to reduce the weight of the leaf spring without any reduction in load carrying capacity and stiffness. Therefore the objective of this paper describes design and FEA analysis of composite leaf spring made of glass fiber reinforced polymer. The dimension of an existing conventional steel leaf spring of commercial vehicle are taken for evaluation of result

Keywords: Leaf spring, Composite material, eglass/epoxy, FEA, ANSYS.

1. Introduction

Springs are crucial suspension elements on cars, necessary to minimize the vertical vibrations, impacts and bumps due to road irregularities and create a comfortable ride. A leaf spring, especially the longitudinal type, is a reliable and persistent element in automotive suspension systems. These springs are usually formed by stacking leafs of steel, in progressively longer lengths on top of each other, so that the spring is thick in the middle to resist bending and thin at the end where it attaches to the body. A leaf spring should support various kinds of external forces but the most important task is to resist the variable vertical forces [1]. Premature failure in the leaf springs by fracture of a leaf was the result of mechanical fatigue caused by a combination of design, metallurgical and manufacturing deficiencies. Fatigue damage started in the vicinity of the leaf central hole by effect of the presence of stress concentrators. Composite materials are superior to all other known structure materials in specific strength and stiffness, high temperature strength, fatigue strength and other properties. The desired combination of properties can be tailored in advance and realized in the manufacture of a particular material. Moreover, the material can be shaped in this process as close as possible to the form of final products or even structural units. Composite materials are complex materials whose components differ strongly from each other in the properties, are mutually insoluble or only slightly soluble and divided by distinct boundaries

2. Literature Review

Mahmood M. Shokrieh, DavoodRezaei (2003) has selected a four-leaf steel spring used in the rear suspension system of light vehicles is analyzed using ANSYS V5.4 software. The 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.

H.A. AI-Quireshi (2000) was designed, fabricated and tested a single leaf variable thickness spring of glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf spring. Study demonstrates that composite can be used for leaf spring for light trucks (jeep) and can meet the requirements together with substantial weight saving [3].

C. Subramanian, S. Senthilvelan (2011) attempts to design and evaluate the performance of double bolted end joint for thermoplastic composite leaf spring. Injection molded 20% glass fiber reinforced polypropylene leaf springs were considered for the joint strength evaluation In spite of unidirectional load being acted at the joint, curved nature of the bearing surface induces bi-axial stresses, which results in severe matrix fibrillation at the bearing surface [4]. Failure morphology under static conditions shows net-tension beside the bearing damage. Failure morphology under fatigue condition revealed net-tension, and shear-out failures besides the bearing damages.

Abdul Rahim Abu Talib, Aidy Ali, G. Goudah, NurAzidaCheLah, A.F. Golestaneh (2010) have developed a finite element models to optimize the material and geometry of the composite elliptical spring based on the spring rate, log life and shear stress parameters. The results showed that the ellipticity ratio significantly influenced the design parameters. Composite elliptic springs with ellipticity ratios of a/b = 2 had the optimum spring parameters [5].

3. Materials Selection

Vertical vibrations and impacts are buffered by variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. The material used directly affects the quantity of storable energy in the leaf spring. The specific strain energy can be written as Eq. (1)

$$S= (1/2) \times ((\sigma t^2)/(\rho E))\text{------------------}(1)$$

Where, σt is the allowable stress,

E is the modulus of elasticity and
ρ is the density.

Table 1: Properties of (65Si7) EN47 Steel leaf spring

Sr. No.	*Parameter*	*Value*
1	Young's Modulus E	2.1×105 MPa
2	Poisson's Ratio	0.266
3	Tensile Strength Ultimate	1272 MPa
4	Tensile Yield Strength	1158 MPa
5	Density	7.86×10-6 Kg/mm3

Table 2: Properties of E-Glass/ Epoxy composite leaf spring

Sr. No.	*Parameter*	*Value*
1	Tensile Strength (MPa)	900
2	Compressive Strength(MPa)	450
3	Possions Ratio	0.217
4	Density (kg/m^3)	$2.16x10^5$
5	Flexural modulus (E) (MPa)	40000

Table 3: Strain Energy Stored By Material (KJ/Kg)

Sr. No.	*Material*	*Strain Energy store by Material (KJ/Kg)*
1	Steel (65Si7)	0.3285
2	E-Glass/ Epoxy	4.5114

Throughout we find the composite material have better mechanical properties than conventional steel as the energy storage capacity of composite material is much higher than steel therefore it is the best material for application selected. Also from eq.1 the material with maximum strength and minimum modulus of elasticity is the most suitable material for leaf spring application.

4. Analysis

Analytical Design for Steel Leaf Spring:
Let,
Total Weight (W) = 2100 N
Thickness (t) = 8 mm
Leaf span, 2L= 860 mm
Width (b) = 60 mm
Total No of Leaves = 3
Now the Maximum Bending stress of a leaf spring is given by the formula [14]
Bending Stress, σb = 6FL / nbt2

= (6*2084*430) / (3*60*82)
= 466.84 MPa

The Total Deflection of the leaf spring is given by [14]

δmax = 6FL3/ Enbt3

= (6*2084*4303) / (2.1*105*3*60*83)
= 51.38 mm
For composite E-Glass/eproxy

FEA Analysis:

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition. The stresses generated in composite leaf spring at full load are shown in fig.1.

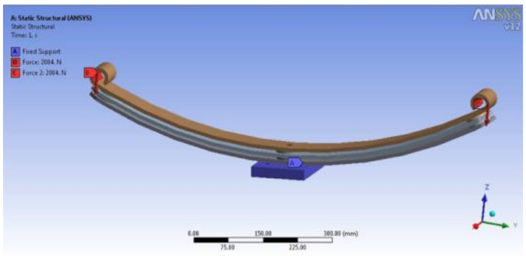

Figure 1: Meshed model of Steel Leaf Spring.

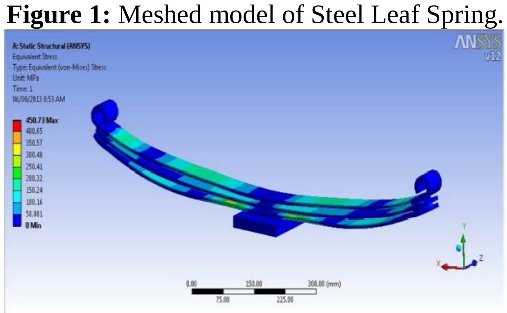

Figure 2: Bending Stresses of Steel Leaf Spring

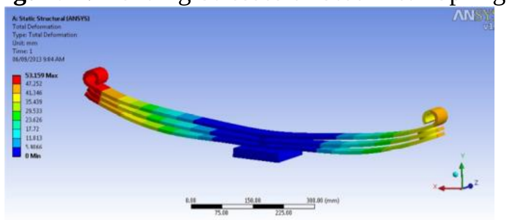

Figure 3: Total Deformation of Steel Leaf Spring.

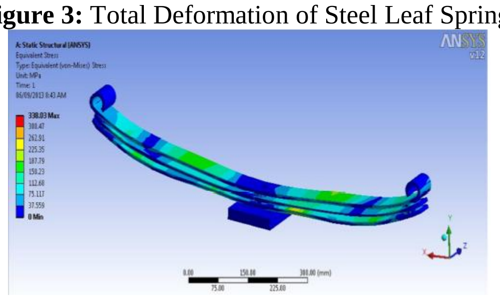

Figure 4: Bending Stresses of Composite Leaf Spring

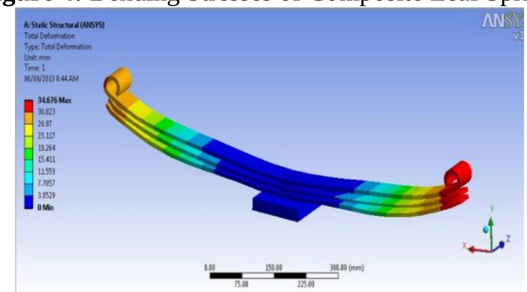

Figure 5: Total Deformation of Composite Leaf Spring

5. Result Table

From the results of static analysis of steel leaf spring, it is seen the displacement of leaf spring is 53.159 mm which is well below the camber length of leaf spring shown in fig.4. It is seen that the maximum bending stress is about 450.73MPa, which less than the yield strength of the material is shown in fig.3. The FEA results are compared with the theoretical results and found that the theoretical result and FEA result are nearer to each other.

Table 4: Result comparison between steel and composite leaf spring

Parameter	*Theoretical Results for steel leaf spring*	*FEA Results for steel leaf spring*	*Variation*
Load, N	4169	4169	NIL
Bending Stress, MPa	466.84	450.73	3.04 %
Total Deflection, mm	51.24	53.159	3.06 %

After that the multi leaf spring with E-Glass/Epoxy material is analyzed in ANSYS-12 with same dimension and same boundary condition as that of conventional leaf spring, showing bending stress and deflection under load in figures.4 & 5. The comparison between steel leaf spring and composite leaf spring for deflection and bending stress results from the ANSYS is shown in the Table 5

Table 5: FEA results comparison between steel and composite leaf spring

Parameter	*FEA Results for steel leaf spring*	*FEA Results for Composite Leaf Spring*	*Variation*
Load, N	4169	4169	NIL
Bending Stress, MPa	450.73	338.03	-25.08 %
Total Deflection, mm	53.159	34.66	-34.77 %

By the comparison of results between steel leaf spring and the composite leaf spring from ANSYS-12 the deflection is decreased by 34.76 % in composite leaf spring that is within the camber range. The bending stresses are decreased by 25.05% in composite leaf spring means less stress induced with same load carrying conditions. The conventional multi leaf spring weights about 10.27kg whereas the E-glass/Epoxy multi leaf spring weighs only 3.26 kg. Thus the weight reduction of 67.88% is achieved. By the reduction of weight and the less stresses, the fatigue life of composite leaf spring is to be higher than that of steel leaf spring. Totally it is found that the composite leaf spring is the better that of steel leaf spring.

Table 6: Percent saving of weight by using composites

Materials	*Weights*	*% weight saving*
Conventional Steel	10.27 kg	-----
E-glass/epoxy	3.26 kg	67.88%

6. Conclusion

In the present work, a steel leaf spring was replaced by a composite leaf spring due to high strength to weight ratio for the same load carrying capacity and stiffness with same dimension as that of steel leaf spring.

- A semi-elliptical multi leaf spring is designed for a four wheel automobile and replaced with a composite multi leaf spring made of E-glass/epoxy composites.
- Under the same static load conditions the stresses and the deflection in leaf springs are found with great difference. Stresses and deflection in composite leaf springs is found out to be less as compared to the conventional steel leaf springs.
- All the FEA results are compared with the theoretical results and it is found that they are within the allowable limits and nearly equal to the theoretical results.
- A comparative study has been made between steel and composite leaf spring with respect to strength and weight. Composite leaf spring reduces the weight by 67.88% for E-Glass/Epoxy.
- E-glass/epoxy composite leaf spring can be suggested for replacing the steel leaf spring both from stiffness and stress point of view.

Totally it is found that the composite leaf spring is the better that of steel leaf spring. Therefore, it is concluded that composite multi leaf spring is an effective replacement for the existing steel leaf spring in vehicles

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