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Design and Analysis of a Composite Leaf Spring for Light Motor Vehicles

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Abstract. Now a days, composite materials are widely used in varieties of engineering applications due to its superior mechanical properties compared to conventional materials. The mechanical properties include high strength to weight ratio, high stiffness, high fracture toughness, high corrosion resistance and low thermal conductivity etc,. In the present scenario, weight reduction is the main criteria in automobile industries. The suspension leaf spring is one of the potential item for weight reduction in automobile as it accounts for ten to twenty percent of the unspring weight. The automotive industries are showing keen interest in replacing of steel spring with composite leaf spring due to high strength to weight ratio. This helps in achieving the vehicle with improved riding qualities. Leaf springs are one of the oldest suspension components, they are still frequently used especially in automotive vehicles. During normal operation, the leaf spring absorbs the vertical vibrations and impacts due to road irregularities by means of spring deflection so that the potential energy is stored in spring as strain energy and then released slowly.

Modeling of mono steel leaf spring and laminated composite leaf springs was done using Pro-E software. Static analysis of both steel and laminated composite leaf springs made of three different materials was carried out at predefined static loading condition using commercially available ANSYS 15.0 software package. Modal analysis is also been performed for mono steel spring and laminated composite leaf spring to determine their natural frequencies and mode shapes. Finally a comparison is made between steel spring and laminated composite leaf spring made of three different materials in terms of stresses, stiffness, natural frequency and percentage weight savings.

Keywords: Composite materials, weight reduction, leaf spring, laminated composite.

1. INTRODUCTION

Senthilkumar Mouleeswaran [1] designed and investigated experimental analysis of composite multi leaf spring using glass fibre reinforced polymer. Compared to steel spring, the composite leaf spring is found to have 67.35% lesser stress, 64.95% higher stiffness and 126.98% higher natural frequency than that of existing steel leaf spring. The conventional multi leaf spring weighs about 13.5 kg whereas the E-glass/Epoxy multi leaf spring weighs only 4.3 kg.

Venkatesan et al [2] developed a composite leaf spring having constant cross sectional area, where the stress level at any station in the leaf spring is considered constant due to the parabolic type of the thickness of the spring, has proved to be very effective. The study demonstrated that composites can be used for leaf springs for light weight vehicles and meet the requirements, together with substantial weight savings. The 3-D modeling of composite leaf spring is done and analyzed using ANSYS.

GulurSiddaramanna et al [3] made general study on design and analysis of a low cost fabrication of complete mono composite leaf spring and mono composite leaf spring with bonded end joints A single leaf with variable thickness and width for constant cross sectional area of unidirectional glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf spring, was designed, fabricated (hand-layup technique) and tested.

Patunkar et al [4] made comparative analysis of conventional steel leaf spring with a virtual model of a composite leaf spring under static load condition only. Under the same static load conditions deflection and stresses of steel leaf spring and composite leaf spring are found with the great difference. Deflection of composite leaf spring is less as compared to steel leaf spring with the same loading condition.

Sri Harsha et al [5] done static analysis of steel leaf spring and laminated composite multi leaf spring using carbon fibre reinforced polymer. Static analysis of 3-D model of conventional leaf spring is performed using ANSYS 12.0. The load carrying capacity, stiffness and weight of composite leaf spring is compared with steel leaf spring analytically. Composite leaf spring.

Fig.1: Assemble set of leaf spring

2. MODELING AND ANALYSIS

Modeling of steel leaf spring is done using Pro-e 15.0 cad software by considering the dimensions of existing leaf spring used in maruti 800 passenger vehicle. Since the leaf spring is symmetrical about the neutral axis, only half part of the leaf spring is modeled by considering it as a cantilever beam. A point load is applied at the middle of the leaf spring in downward direction. The solid model of steel leaf spring is shown in the Fig.2.

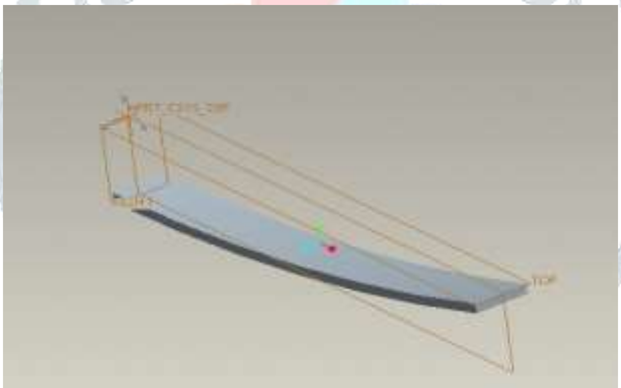

Fig. 2. Solid Model of Steel Leaf Spring

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time-varying loads. A static analysis can, however, include steady inertia loads (such as gravity and rotational velocity), and time-varying loads that can be approximated as static equivalent loads.

Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis. Model was shown in Fig 3.

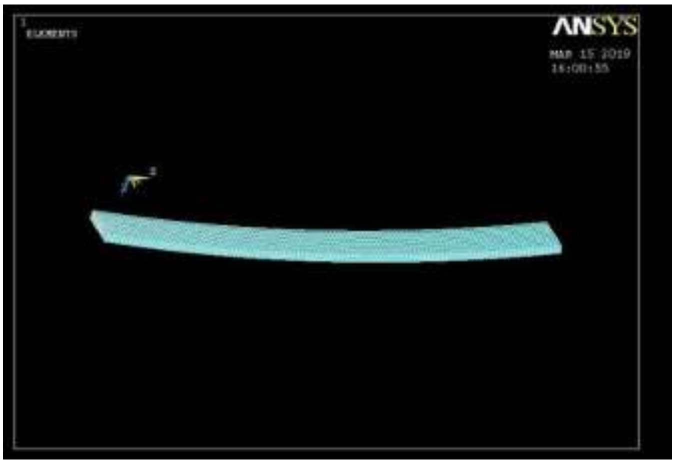

Fig. 3 Laminated Model of E-Glass / Epoxy Composite Leaf Spring

Material properties for preparing laminated composite leaf spring are listed in Table 1.

Table.1. Material Properties of Composite Materials

Material properties	**E-Glass/ Epoxy**	**S-Glass/ Epoxy**	**Carbon/ Epoxy**
Fiber Volume Fraction, %	50	50	50
Extensional Elastic Modulus MPa	39E+3	43E+3	142E+3
Transverse Elastic Modulus, MPa	8.6E+3	8.9E+3	10.3E+3
In-plane Shear Modulus, G_{12}	3.8E+3	4.5E+3	7.2E+3
Major Poisson's Ratio, ν_{12}	0.28	0.27	0.27
Minor Poisson's Ratio, ν_{21}	0.06	0.06	0.02
Density, ρ kg/mm^3	2.1E-6	2E-6	1.59E-6

3. RESULTS AND DISCUSSION

Static analysis of steel leaf spring is performed using ANSYS 15.0 analysis software, by considering the pre-determined conditions (necessary boundary conditions and loads) to achieve the results with in the allowable limits.

From the static analysis, deflection and Von- mises stress of steel leaf spring are 36.13 mm and 498.19 MPa.

FE analysis is carried out using ANSYS 10.0 software to determine stresses and deflections. For this a load of 795N is applied at the middle of the eye end. The displacement is constrained along X and Z directions in the middle of the leaf spring and along all directions at the eye end. Fig. 4. shows the boundary conditions at both ends and a point load applied at the middle of the leaf spring.

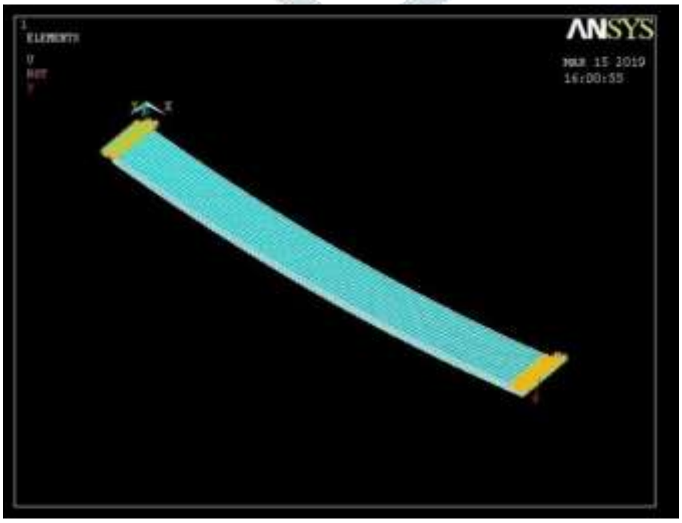

Fig. 4. Meshed Model of Mono Laminated Composite Leaf Spring with Boundary Conditions.

Static analysis of mono laminated composite leaf spring, the displacements of the E-glass / epoxy, S-glass / epoxy, Carbon / epoxy are 46.54 mm, 42.42 mm and 12.89 mm. And the corresponding Von-Mises stress values are 256.05 MPa, 256.32 MPa and 262.57 MPa.

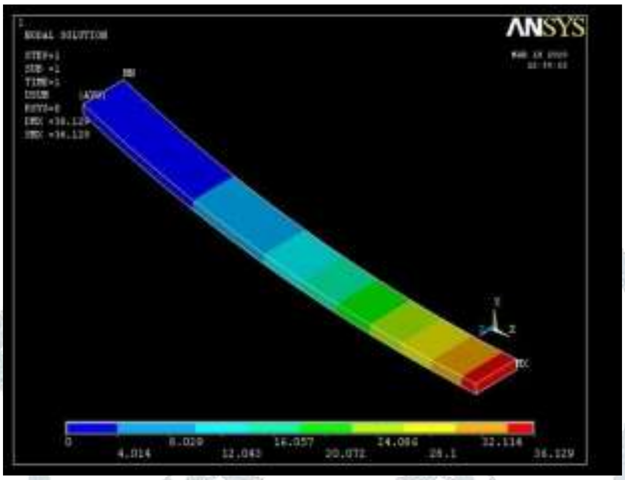

Fig.5: Deflection Plot of Steel Leaf Spring

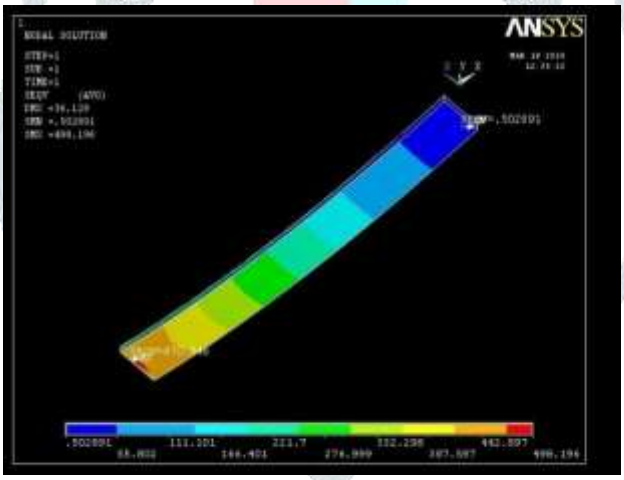

Fig. 6. Von-Mises Stress Plot of Steel Leaf Spring

From the modal analysis, the natural frequency of steel leaf spring is found to be 1.072 Hz. While that of laminated composite leaf springs (i.e E-glass / epoxy, S- glass / epoxy and Carbon / epoxy) are 1.466 Hz, 1.578 Hz and 3.214 Hz.

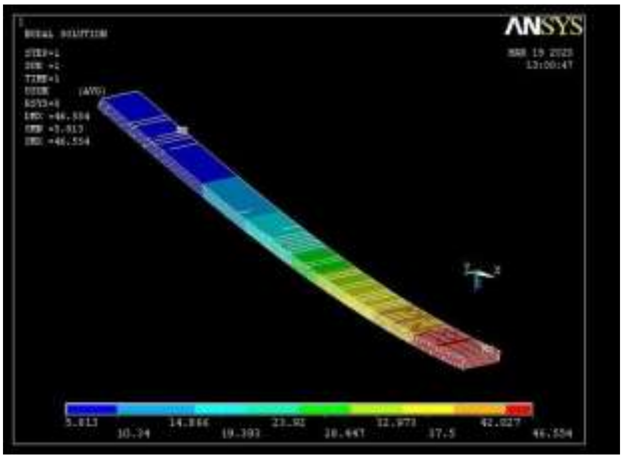

Fig. 7 Deflection Plot of E-glass / epoxy Laminated composite Leaf Spring

Analytical results obtained for conventional steel & laminated mono composite leaf springs using ANSYS 15.0 is shown in the table 2.

Table 2.Analytical Results

Material Type	Fiber Orientation	Deflection (mm)	Stress(Mpa)	
			Max(Mpa)	Min(Mpa)
Steel		36.129	498.196	0.503
E-glass/epoxy	(0,0,0,0)	46.54	256.05	0.5324
S-glass/epoxy	(0,0,0,0)	42.42	256.318	0.5308
Carbon/epoxy	(0,0,0,0)	12.889	262.567	0.3367

Weight of leaf spring is reduced by the replacement of steel one with composite materials. And the percentage of weight reduction is calculated and is shown in the table 3.

Table 5.7. Percentage Weight Reduction

Material	Weight (Kg)	% Weight Reduction
Steel	3.79	-----------
E-Glass / Epoxy	1.013	74
S-Glass / Epoxy	0.965	76
Carbon / Epoxy	0.762	79.89

Mono laminated composite leaf spring reduces the weight by 74% for E-glass / epoxy, 76% for S-glass / epoxy and 79.89% for Carbon / epoxy.

The weight of the leaf spring is reduced considerably about 80% by replacing steel leaf spring with Carbon / epoxy laminated composite leaf spring.

The displacements and stresses of laminated composite leaf springs (i.e E-glass / epoxy, S-glass / epoxy & Carbon / epoxy) are less compared to steel spring.

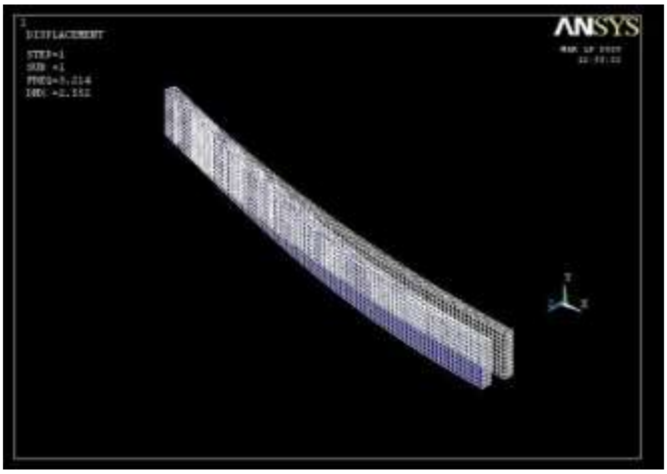

Fig. 8. Natural Frequency Plot of Carbon / Epoxy Laminated Composite Leaf Spring

4. CONCLUSION

The replacement of steel leaf spring with laminated composite leaf spring leads to the following conclusions.

- From the static analysis results, it is observed that the von-mises stress in the steel leaf spring is 498.2 MPa. And that of

laminated one (i.e in E-glass / epoxy, S- glass / epoxy and Carbon / epoxy) are 256.05 MPa,
256.318 MPa, and 262.567 MPa.

- The mono laminated composite leaf spring is modeled for the same stiffness as that of the steel leaf spring. It is found that the stiffness of all the composite leaf springs is more when compared with that of steel leaf spring. The stiffness of steel leaf spring is 23.37 N/mm and similarly stiffness of E-glass / epoxy, S-glass / epoxy and Carbon / epoxy composite leaf springs are 17.06 N/mm, 18.73 N/mm and
61.64 N/mm respectively

- Convectional steel leaf spring was found to weigh 3.9 kg where as mono laminated (i.e E-glass / epoxy, S-glass / epoxy and Carbon / epoxy) composite leaf springs are found to weigh 1.013 kg, 0.965 kg and 0.762 kg. The percentage of weight reduction is 74% for E-glass / epoxy, 75.25% for S-glass / epoxy and 79.89% for Carbon / epoxy.

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