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Research Paper

DESIGN OF SINGLE COMPOSITE LEAF SPRING FOR LIGHT WEIGHT VEHICLE

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The automobile industry has shown increased interest in the replacement of steel spring with fiberglass composite leaf spring due to high strength to weight ratio. In this paper reducing weight of vehicles and increasing or maintaining the strength of their spare parts is considered. As leaf spring contributes considerable amount of weight to the vehicle and needs to be strong enough, a single E-glass/Epoxy leaf spring is designed following the design rules of the composite materials considering static loading only. The constant cross section design of leaf springs is employed to take advantages of ease of design analysis and its manufacturing process. And it is shown that the resulting design stresses are much below the strength properties of the material, satisfying the maximum stress failure criterion. The designed composite leaf spring has also achieved its acceptable fatigue life. This particular design is made specifically for light weight vehicles.

Keywords: Steel spring, E-glass/Epoxy, Static load

INTRODUCTION

Weight reduction has been the main/primary focus of automobile manufactures. Suspension leaf spring, a potential item for weight reduction in automobiles, accounts for 10-25% of unsprung weight. Application of composite materials reduces the weight of leaf spring without any reduction on the load carrying capacity and stiffness in automobile suspension system (Daugherty, 1981).

A composite material is the combination of two or more materials that produce a synergistic effect so that the combination produces aggregate properties that are different from any of those of its constituents attain independently. This is intentionally being done today to get different design, manufacturing as well as service advantages of products. Up on those products leaf spring is the focus of this project for which researches

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are running to get the best composite material, which meets the current requirement of strength and weight reduction in one, to replace the existing steel leaf spring (Robert, 1999).

Leaf spring should absorb vertical vibrations due to road irregularities by means of variations in the spring deflection so that potential energy is stored in the spring as strain energy and then released slowly. So, increasing energy storage capability of a leaf spring ensures a more compliant suspension system. A composite mono-leaf spring has been designed and their end joints are analyzed and tested for a light weight vehicle. 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 (Shiva Shankar and Vijayarangan, 2006).

Design and experimental fatigue analysis of composite multi leaf spring using glass fiber reinforced polymer are carried out using life data analysis, in this particular literature. 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. Thus the weight reduction of 68.15% is achieved. Besides the reduction of weight, the fatigue life of composite leaf spring is predicted to be higher than that of steel leaf spring (Senthilkumar and Mouleeswaran, 2012).

Life data analysis is found to be a tool to predict the fatigue life of composite multi leaf spring. It is found that the life of composite leaf spring is much higher than that of steel leaf spring by using three dimensional finite element method of analysis. They pointed that the leaf spring behaves like a simply supported beam and the flexural analysis is done considering it as a simply supported beam. The simply supported beam is subjected to both bending stress and transverse shear stress. Flexural rigidity is an important parameter in the leaf spring design and test out to increase from two ends to the centre. Researchers tried to access three design approaches: I. Constant thickness and varying width, II. Constant width and varying thickness, and III. Constant thickness and constant width design. Out of these mentioned design concepts, the constant cross-section design method is selected due to its capability for mass production and accommodation of continuous reinforcement of fibers. Since the cross-section area is constant throughout the leaf spring, same quantity of reinforcement fiber and resin can be fed continuously during manufacturing. It is also quite suitable for filament winding process (Venkatesan and Devaraj, 2012).

Rajiv, Pradeep, Shivashankar and Vijayarangan stated that taking the advantages of mass production and continuous fiber accommodation, composite leaf spring with constant cross sectional area is designed using Genetic Algorithm (GA) method. The weight of the composite leaf spring can be reduced by 53.5% by applying the GA optimization technique. Composite mono leaf spring reduces the weight by 85% for E-Glass/

Epoxy over conventional leaf spring. The reduction of 93% weight is achieved by replacing conventional steel spring with an optimally designed composite mono-leaf spring (Rajiv *et al.*, 2007). This project covers the design, of the single E-glass/Epoxy composite leaf spring for a light weight vehicle. But the design is limited to the static loading only.

DESIGN SPECIFICATIONS

Here Weight and initial measurements of four wheeler "Model: TATA-Ace light vehicle are taken.

Weight of vehicle = 1200 kg

Straight length of the leaf spring (L) = 1072 mm

Maximum load carrying capacity = 750 kg

Total weight = 1200 + 750 = 1950 kg;

Taking factor of safety (FS) = 2,

Acceleration due to gravity (g) = 10 m/s^2

Therefore: Total Weight
(W') = 1950 x 10 x 2 = 39000 N

Since the vehicle is 4-wheeler, a single leaf spring corresponding to one of the wheels takes up one fourth of the total weight, i.e., F = 39000/4 = 9750 N

DESIGN OF COMPOSITE LEAF SPRING

Based on the specific strain energy of steel spring and some composite materials, the E-Glass/Epoxy is selected as the spring material. Many attempts have been made to substitute more economic resins for the epoxy but all attempts to use polyester or vinyl ester resins have been unsuccessful to date. The stored elastic strain energy in a leaf spring varies directly with the square of maximum allowable stress and inversely with the modulus of elasticity both in the longitudinal and transverse directions according to (for notations please refer on notation chapter):

$$S = \frac{\pm_t^2}{2 \circ E}$$

A life data analysis method is used. Two constants in their relation on the basis of experimental results are proposed. It is proved that the analytical formula predicts the fatigue life of component with E-Glass/Epoxy composite material, using Hwang and Han relation (Kumar and Vijayarangan, 2007).

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

B = 10.33 and C = 0.14012

$$r = \frac{\pm_{\max}}{\pm_u}$$

From the material point of view a Glass/Epoxy composite material is selected. It is selected due to its relative advantages stated in the literature review above, mainly high strength to weight ratio and high capacity of storing strain energy in the longitudinal direction of the fibers.

The properties of Glass/Epoxy composite material are given as follows:

E_1 (modulus of elasticity along the longitudinal direction) = 54 GPa,

E_2 (modulus of elasticity along the longitudinal direction) = 18 GPa,

G_{12} (shear modulus) = 9 GPa,

$^3{}_{12}$ (major poison's ratio) = 0.25

X_t = 1035 Mpa, Y_t = 28 Mpa, X_c = 1035 Mpa, Y_c = 138 Mpa, S = 41 Mpa

From Shiva Shankar and Vijayarangan (2006) for E-glass/Epoxy;

Maximum stress ($\pm_{max}$) = 473 Mpa

Maximum deflection (¢_{max}) = 105 mm

Measured data of the above stated light weight four-wheeler vehicle:

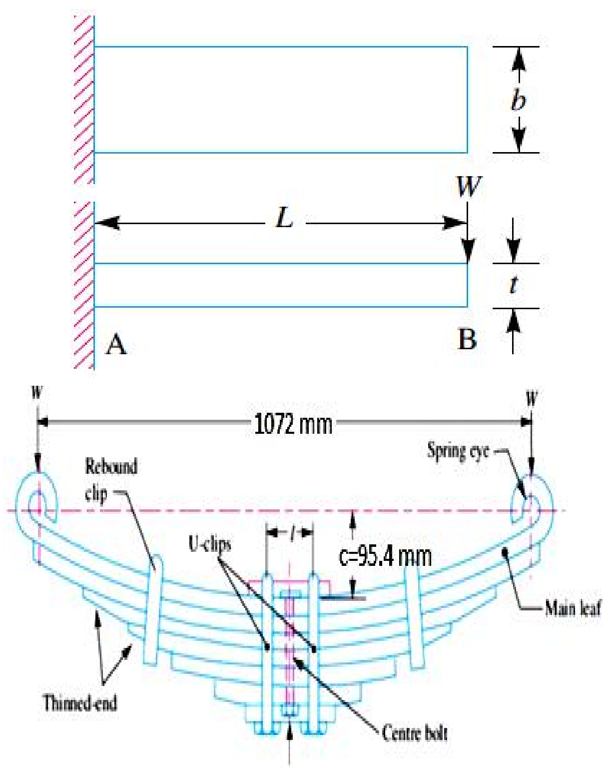
Straight length of the leaf spring (L) = 1072 mm

The ratio of camber length to leaf span is given by Manas Patnaik *et al.* (2012): $C/L = 0.089$

Thus $C = 0.089 \times L = 0.089 \times 1072 =$ 95.4 mm

Since the leaf spring is fixed with the axle at its centre, only half of it is considered for analysis purpose (Khurmi and Kupta, 2000).

Figure 1: Leaf Spring (Notations Chapter is Provided Next to Conclusion)



Since analyzing 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, $L/2$ = 536 mm, F = 9750 N, t = ? and b = ?

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

From equations of strength of materials we have

$$\pm_{max} = \frac{6FL}{bt^2} \text{ and } \text{¢}_{max} = \frac{4FL^2}{Ebt^2}$$

Solving these two equations the thickness and width of the leaf spring can be formulated, respectively, as follows:

$$t = \frac{\pm_{max} L^2}{E\text{¢}_{max}};\ b = \frac{6FL}{\pm_{max} t^2}$$

Since we consider half of the leaf spring we substitute '$L/2$' instead of 'L' to calculate '*t*' and '*b*'. As the ends of the leaf spring are hinged, the entire leaf spring will only be loaded under tension. Therefore, we consider only the longitudinal properties.

$$t = \frac{473 \times 10^6 \times 536^2 \times 10^{-6}}{54 \times 10^9 \times 105 \times 10^{-3}} = 24\ mm;$$

$$b = \frac{6 \times 9750 \times 536 \times 10^{-3}}{473 \times 10^6 \times 24^2 \times 10^{-6}} = 115\ mm;$$

$$\pm_b = \frac{M * Y}{t} = \frac{5226 \times 0.012}{1.34 \times 10^{-7}} = 473\ MPa\ ;$$

where

$$Y = \frac{t}{2}\ I = \frac{bt^3}{12}\ M = F \times L$$

Since we use unidirectional orientation of fibers and pure tensile loading nature of the leaf spring is considered, we took plane stress condition as the leaf is thin plate. Thus the bending stress, completely, is responsible to the longitudinal stress so

$$\pm_1 = \pm_b$$

Stress along the transverse direction

$$\pm_2 = \frac{F}{b \times L} = \frac{9750}{115 \times 536 \times 10^{-6}} = 0.158\ Mpa$$

The shear stress

$$² = \frac{F}{A} = \frac{9750}{115 \times 24 \times 10^{-6}} = 3.5\ Mpa$$

Now we need to calculate the strains of the product model of the leaf spring.

$$\begin{bmatrix} £_1 \\ £_2 \\ ¥_{12} \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} & 0 \\ s_{12} & s_{22} & 0 \\ 0 & 0 & s_{66} \end{bmatrix} \begin{bmatrix} \pm_1 \\ \pm_2 \\ ²_{12} \end{bmatrix}$$

$$s_{11} = \frac{1}{E_1} = 18.5 \times 10^{-12}\, pa^{-1};$$

$$s_{12} = \frac{-¥_{12}}{E_1} = -4.63 \times 10^{-12}\, pa^{-1};$$

$$s_{22} = \frac{1}{E_2} = 55.6 \times 10^{-12}\, pa^{-1};$$

$$s_{66} = \frac{1}{G_{12}} = 111.1 \times 10^{-12}\, pa^{-1};$$

Thus substituting these from the above equations,

$$£_1 = 0.070;\ £_2 = 0.017;\ ¥_{12} = 3.88 \times 10^{-4}$$

Deflection

$$¢_{max} = \frac{4FL^3}{Ebt^3} = \frac{4 \times 9750 \times 536^3}{54000 \times 115 \times 24^3} = 69.9\ mm$$

We can calculate the fatigue life, number of cycles to fail, of the composite leaf spring using Equation

$$N = [B(1-r)]^{1/c} = [10.33 \times (1 - 0.457)]^{1/0.14012}$$

$= 221.16 \times 10^3$ cycles ; where $r = \frac{\pm_{max}}{\pm_u} = 0.457$

$= 0.457$

RESULTS AND DISCUSSION

Since the shear stress is 3.5Mpa multiplied by a factor of '9' (9 x 3.5 = 31.5 Mpa) is much less than the shear strength ($²_u$ = 41 Mpa) of the specified composite material, E-glass/ Epoxy. Specifying the criteria ($9 < ²_{12} < ²_u$), design is safe even for the flexural failure. Using maximum stress failure criterion, the design results as follows:

When we compare the values Table 1, the design 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 deflection of the leaf spring along its transverse direction, which is very small compared to the considered maximum deflection $¢_{max}$(105 mm) and the camber C (95.4 mm). The fatigue life of the designed single E-glass/Epoxy composite leaf spring is predicted and obtained as $N = 221.16 \times 10^3$ cycles. This shows the acceptable life or good resistance of the material to failure under fatigue loading.

Table 1: Compression of Strength Properties

Strength Properties	Design Strength	Design Strain	Deflection
X_t = 1035 Mpa	$\pm_1$ = 473 Mpa	$£_1$ = 0.070	69.9 mm
Y_t = 28 Mpa	$\pm_2$ = 0.158 Mpa	$£_2$ = 0.070	
$²_u$ = 41 Mpa	² = 3.5 Mpa	$¥_{12} = 3.88 \times 10^{-4}$	

CONCLUSION

As reducing weight and increasing strength of products are high research demands in the world, composite materials are getting to be up to the mark of satisfying these demands. In this paper reducing weight of vehicles by 68.14% and increasing the strength of their spare parts is considered. A mono composite leaf spring for the vehicular suspension system was designed using E-Glass/Epoxy with the objective of minimizing weight of the leaf spring. And it is shown that the resulting design stresses are much below the strength properties of the material satisfying the maximum stress failure criterion. The deflection of the leaf spring along its transverse direction, which is very small compared to the considered maximum deflection. Even though it has been noted the material is not that reliable due to chipping problem in a bumpy roads by former studies, it has achieved an acceptable fatigue life of 221 x 10^3 cycles. This particular design is made specifically for the case study/TATA-Ace/light weight vehicles.

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APPENDIX

Notations

$\pm_{max}$ – maximum stress (MPa);

$\pm_u$ – ultimate tensile strength (MPa);

r – applied stress level;

N – number of cycles to failure;

C – camber length;

L – leaf span;

£$_{ij}$ – strain matrix;

S_{ij} – compliance matrix;

$\pm_{ij}$ – stress matrix;

$\pm_2$ – stress along the transverse direction (MPa);

² - shear stress (MPa);

¢$_{max}$ – Maximum deflection (mm);

S – strain energy;

$\pm_t$ – allowable stress;

E – modulus of elasticity;

° – the density;

X_t and X_c are longitudinal tensile and compressive strengths respectively;

Y_t and Y_c are transverse tensile and compressive strengths respectively;

²$_u$ – shear strength;

b – width of the leaf spring; t-thickness of the leaf spring.