OPTIMAL DESIGN OF LEAF SPRINGS USING COMPOSITE MATERIALS

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Abstract

The present work is to emphasizing the reduction in weight of suspension system by using composite materials instead of customary leaf springs. Also improve the level of suspension by using of composite materials. The leaf spring is one of the potential items for weight reduction in automobiles as it accounts for 10% - 20% of the unsprung weight. The process is beginning with the selection of composite materials. The selection process is focused to the checking of property of the material be chosen. After the verification, the manufacturing is done by the proper methods. Then the design calculation is done for both ordinary and novel spring system. Based on the results, the design calculation for deflection and weight of springs is compared.

Key words: Suspension Systems, Leaf Spring, Unsprung weight, Composite, Weight Reduction.

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. This achieves the vehicle with more fuel efficiency and improved riding qualities. 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. In every automobile, i.e. four wheelers and railways, the leaf spring is one of the main components and it provides a good suspension and it plays a vital role in automobile application. It carries lateral loads, brake torque, driving torque in addition to shock absorbing. The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. Investigation of composite leaf spring in the early 60's failed to yield the production facility because of inconsistent fatigue performance and absence of strong need for mass reduction. Researches in the area of automobile components have been receiving considerable attention now. Particularly the automobile manufacturers and parts makers have been attempting to reduce the weight of the vehicles in recent years. Emphasis of vehicles weight reduction in 1978 justified taking a new look at composite springs.

2. Literature review

Investigation of composite leaf spring in the early 60's failed to yield the production facility because of inconsistent fatigue performance and absence of strong need for mass reduction. Researches in the area of automobile components have been receiving considerable attention now. Several papers were devoted to the application of composite materials for automobiles I.RAJENDRAN (2006) studied the application of composite structures for automobiles and design optimization of a composite leaf spring. Great effort has been made by the automotive industries in the application of leaf springs made from composite materials. S. VIJAYARANGAN (2006) showed the introduction of fiber reinforced plastics (FRP) made it possible to reduce the weight of a machine element without any reduction of the load carrying capacity. The introduction of plastics makes massive changes in manufacturing sectors. Mr. Ballinger (1995) gives a new approach to manufacturing of metals by using derivatives of plastics. And he was the first man to introduce reinforced plastics in metal manufacturing. A.P. Ghodake and K.N. Patil (2013) are taken into the next level. They tried to manufacture spring on polymer resins. Achamyeleh A Kassie, R Reji Kumar (2014) are design the leaf spring using composite materials for light weight vehicles with adequate fatigue life.

3. Materials and Methods

Materials constitute nearly 60%-70% of the vehicle cost and contribute to the quality and the performance of the vehicle. Even a small amount in weight reduction of the vehicle, may have a wider economic impact. Composite materials are proved as suitable substitutes for steel in connection with weight reduction of the vehicle. Hence, the composite materials have been selected for leaf spring design.

3.1 Fiber Selection

The commonly used fibers are carbon, glass, Kevlar, etc. Among these, the glass fiber has been selected as the core leaf based on the cost factor and strength and the carbon fiber is selected as the laminate over the core leaf. The types of glass fibers are C-glass, S-glass and E-glass. The C-glass fiber is designed to give improved surface finish. S-glass fiber is design to give very high modular, which is used particularly in aeronautic industries. The E-glass fiber is a high quality glass, which is used as standard reinforcement fiber for all the present systems well complying with mechanical property requirements. Thus, E-glass fiber was found appropriate for this application. And for carbon fiber there are several type of fibers based on properties, on precursors and on heat treatment temperature. After a long analysis and study TYPE II intermediate heat treatment carbon fiber is taken, where final heat treatment temperature should be around 1500 degrees Celsius and can be associated with high strength type fiber.

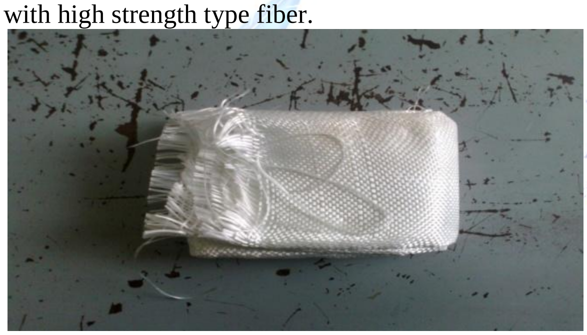

Fig 1: E-glass fiber

3.2 Resin Selection

Many thermo set resins such as polyester, vinyl ester, epoxy resin are being used for Fiber Reinforcement Plastics (FRP) fabrication. Among these resin systems, epoxies show better inter laminar shear strength and good mechanical properties. Hence, epoxide is found to be the best resins that would suit this application. Different grades of epoxy resins and hardener combinations are classifieds based on the mechanical properties. Among these grades, the grade of epoxy resin selected is Dobeckot 520 F and the grade of hardener used for this application is 758. Dobeckot 520 F is a solvent less epoxy resin. This in combination with hardener 758 cures into hard resin. Hardener 758 is a low viscosity polyamine. Dobeckot 520 F, hardener 758 combinations is characterized by

- Good mechanical and electrical properties.
- Faster curing at room temperature.
- Good chemical resistance properties.

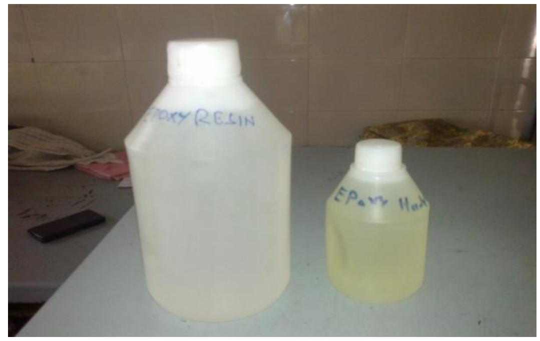

Fig 2: Epoxy resin and hardener

3.3 E-Glass Fiber

E-Glass or electrical grade glass was originally developed for standoff insulators for electrical wiring. It was later found to have excellent fiber forming capabilities and is now used almost exclusively as the reinforcing phase in the material commonly known as fiberglass. Carbon fiber is a high tensile fibers alternatively called as graphite fiber. It has superior properties than any other fiber or equivalent material. The carbon atoms in the fiber are bonded together in crystals that are more or less aligned parallel to the axis of the fiber

3.4 Fiber Manufacture

Glass fibers are generally produced using melt spinning techniques. These involve melting the glass composition into a platinum crown which has small holes for the molten glass to flow. Continuous fibers can be drawn out through the holes and wound onto spindles, while short fibers may be produced by spinning the crown, which forces molten glass out through the holes centrifugally. Fibers are cut to length using mechanical means or air jets. Each carbon fiber is produced from a precursor polymer such as poly-acrylonitrile, rayon or petroleum pitch. The precursor is first spun into filament yarns, using chemical and mechanical processes to initially align the polymer atoms in a way to enhance the physical properties of the completed carbon fiber. The drawn from filament yarning they are heated to drive off non carbon atoms, this process is called as carbonization, producing finally the carbon fiber. Fiber dimension and to some extent properties can be controlled by the process variables such as melt temperature (hence viscosity) and drawing/spinning rate. The temperature window that can be used to produce a melt of suitable viscosity is quite large, making this composition suitable for fiber forming.

As fibers are being produced, they are normally treated with sizing and coupling agents. These reduce the effects of fiber-fiber abrasion which can significantly degrade the mechanical strength of the individual fibers. Other treatments may also be used to promote wetting and adherence of the matrix material to the fiber.

3.5 Composition

E-Glass is a low alkali glass with a typical nominal composition of SiO_2 54wt%, Al_2O_3 14wt%, CaO + MgO 22wt%, B_2O_3 10wt% and Na_2O+K_2O less than 2wt%. Some other materials may also be present at impurity levels. Carbon fiber is composition of (i) about 90 to 99.9% by weight carbon fiber,(ii) a total of 0.1% to 10% by weight at least one vinyl additional polymer having at least one oxidant ring , said vinyl additional polymer being prepared by polymering one or more ethylene unsaturated compounds.

Table 1: Properties of E-Glass / Epoxy

SPECIFICATION	VALUES
Material selected	E-glass/Epoxy
Tensile strength	800 N/mm^2
Young's modulus(E)	$3.86x10^4$ N/mm^2
Design stress (σ_b)	328 N/mm^2
Total length (2L)	960 mm
Static loading (P)	2050 N
spring width (w)	60 mm
Spring weight	0.8 kg
Density (ρ)	2.6 kg/mm^3
Thickness (t)	8 mm

Table 2 Properties of Carbon Fiber

SPECIFICATION	VALUES
Material selected	Carbon fiber
Tensile strength	110 N/mm^2
Young's modulus(E)	$7.0x10^4$ N/mm^2
Total length (2L)	960mm
spring width (w)	60mm
Density (ρ)	1600 kg/m^3

Table 3: Properties of Steel leaf spring

SPECIFICATION	VALUES
Material selected	Steel 55Si2Mn90
Tensile strength	1962 N/mm^2
Yield strength	1470 N/mm^2
Young's modulus(E)	$2.1x10^5$ N/mm^2
Total length (2L)	960 mm
Static loading (P)	1820 N
spring width (w)	60 mm
Spring weight	2.95 kg
Density (ρ)	7.8 kg/mm^3
Thickness (t)	6mm

3.6 DESIGN CALCULATION

3.6.1 Design of Steel Leaf Spring

1. Material selection:

To select the suitable material from the table 55SiMn90

Where,

Yield strength = 1470 N/mm^2

Young's modulus = $2.1*10^5$ N/mm^2

2. No of leaves:

$$n = n_e + n_g$$

Where,

n_e - No of full length leaves

n_g - No of graduated leaves

n = 2+1

n = 3 leaves

3. Specification of leaf spring:

Effective length (2L) = 960mm

L = 480mm

Width (w) = 60mm

Thickness (t) = 6mm

4. To find the load

$$\sigma_b = \frac{6*P*L}{n*b*t^2}$$

Where,

σ_b = 0.5 * yield strength

= 0.5 * 1470 N/mm^2

= 808.5 N/mm^2

L = 480mm

n = 3

b = 60mm

t = 6mm

$808.5 = \frac{6*P*480}{3*60*6^2}$

P = 1819.12 N

Where, the selection of the leaves width & thickness in between the range from 45 to 100mm width, 5 to 16mm thickness. So that design of leaf is safe.

5. Calculate radius of curvature and camber:

R = $L^2 / 2y$

Max. Deflection of $= \frac{12PL^3}{bt^3(3ne+ng)}$

$= \frac{12*1819.12*480^3}{2.1*10^5*60*6^3*(3*2+2*1)}$

y =110.88 mm

Radius of Curvature, R= $L^2 / 2y$

$= 480^2 /2*110.88$

= 1038.96 mm

Camber =0.5 * deflection

=0.5 * 110.88

=55.44 mm

6. Load on bolt:

$P_b = \frac{2P n_e n_g}{n(3n_e - 2n_g)}$

$= \frac{2*1819.12*1*2}{3*(3*2 - 2*1)}$

P_b = 606.37 N

7. Design of pin:

Width of master leaf b= 60 mm

Length of pin b' = b+2*clearance

b' = 60+2*2.5

Where the clearance taken 1.5 to 2.5

b'= 65 mm

Consider bearing of the pin in the eye

d_p*b*P_b = load on the pin

Where

d_p - dia of the pin

P_b - allowable bearing pressure

(Assume 10 N /mm^2)

Load on pin = $\frac{P}{\cos\alpha}$

= 1819.12 cos 45

Load on pin = 2572.62 N

$d_p = \frac{2572.62}{60 * 10}$

d_p = 4.28 mm

= 5mm (approximately)

8. Check for pin:

i) Check for bending

$M = \frac{\text{load on pin} * b'}{4}$

$= \frac{2572.62 * 65}{4}$

M = 41805.07 N-mm

By equating the bending moment to the resisting of the pin

M = $\sigma_b *\pi/32 *d_p^3$

41805.07 = $\sigma_b *\pi/32 *5^3$

σ_b = 3406.58N/mm^2<8*10^4 N/mm^2

The induced stress should not exceed the permissible stress. So that design safe.

ii) Check for shear stress

$2* \pi/4 *d_p^2 *\tau$ = load on pin

$2* \pi/4 *5^2 *\tau$ = 2572.62

τ = 65.51 N/mm^2 < 120 N/mm^2

The induced stress will not exceed the permissible stress. So that design is safe.

3.6.2 Design of Composite Leaf Spring

1. Material selection:

To select the suitable material

E-glass/Epoxy

Where,

Young's modulus (E)= 3.86*10^4 N/mm^2

2. No of leaves:

n = $n_e + n_g$

Where,

n_e - No of full length leaves

n_g - No of graduated leaves

n = 2+1

n = 3 leaves

3. Specification of leaf spring:

Effective length (2L)=960mm L

Width (w) = 60 mm

Thickness (t) = 10 mm

4. To find the load:

$\sigma_b = \frac{6*P*L}{n*b*t^2}$

Length (L) = 480mm

No of leaves = 3

Width (w) = 60mm

Thickness (t) = 10mm

$328 = \frac{6*P*480}{3*60*10^2}$

P = 2050 N

Where, the selection of the leaves width & thickness in between the range from 45 to 100mm width, 5 to 16mm thickness.

So that design of leaf is safe.

5. Calculate radius of curvature and camber :

R = $L^2 / 2y$

Maximum deflection = $\frac{12PL^3}{Ebt^3(3n_e+2n_g)}$

$= \frac{12*2050*480^3}{3.86*10^4*60*10^3(3*2+2*1)}$

$y = 146.83mm$

$R = \frac{480^2}{2*146.83}$

$= 784.58mm$

Camber = 0.5*deflection

= 0.5*146.83

Camber = 73.41mm

6. Load on bolt:

$P_b = \frac{2*P*n_g*n_e}{n(3n_e - 2n_g)}$

$= \frac{2*2050*1*2}{3(3*2 – 2*1)}$

$P_b = 683.33$ N

7. Design of pin:

b =60mm

Length of pin b'=b+2*clearance

b' = 60+2*2.5

b' = 65 mm

Consider bearing of the pin in the eye

d_p*b*P_b = load on the pin

P_b - allowable bearing pressure

(Assume 10 N/mm^2)

Load on pin = $\frac{P}{\cos \alpha}$

$= \frac{2050}{\cos 45}$

Load on pin = 2899.13 N

$d_p = \frac{2899.13}{60*10}$

$d_p = 4.83$

= 5mm (approximately)

8. Check for pin:

i) Check for bending

Maximum bending moment M = $\frac{\text{load on pin * b'}}{4}$

$= \frac{2899.13*65}{4}$

M=47110.86 N-mm

By equating the bending moment to the resisting moment of the pin

$M = \sigma_b*\pi/32*d_p^3$

$47110.86 = \sigma_b*\pi/32*5^3$

$\sigma_b = 3838.94 N/mm^2 < 5.5*10^5 N/mm^2$

The induced stress should not exceed the permissible stress. So that design is safe.

ii) Check for shear stress

$2*\pi/4*d_p^2*\tau$ = load on pin

$2*\pi/4*5^2*\tau = 2899.13$

$\tau = 73.82 N/mm^2 < 85 N/mm^2$

The induced stress will not exceed the permissible stress. So that design is safe.

4 Results and Discussion

Material = E-glass/Epoxy
Effective length (2L) = 960mm
Width (w) = 60mm
Thickness (t) = 10mm
No of leaf (n) = 3
Full length leaves (n_e) = 2
Graduated leaves (n_g) = 1
Radius of curvature (R) = 784.58mm
Camber = 73.41mm
Deflection(y) = 146.83m
Specific weight = 2.95 kg

The above values are expressing the properties of composite leaf spring after the manufacturing.

Material = 55Si2Mn90
Width (w) = 60mm
Thickness (t) = 6mm
No of leaves (n) = 3
Full length leaves = 2
Graduated leaves = 1
Radius of curvature(R) =1038.96mm
Camber = 55.44mm
Maximum deflection(y) = 110.88mm
Effective length (2L) = 960mm
Specific weight = 0.8 kg

The accessible leaf spring's calculation results are listed above. Among the two values of existing and new model there is a significant change in the specific weight and deflection of the springs. It shows that the deflection and weight of the new suspension system is well again than existing type.

5 Conclusions

The results of a calculation part is concluded are,

- That the specific weight of the normal spring is 2.95kg and the new system having only 0.8kg.
- The normal leaf spring is 3.6 times weights than composite leaf spring. And also the deflection of the normal spring is 110.8mm.nevertheless the new system having 146.83mm.
- So, the composite spring system is light weight and also it has better suspension level compared to the Steel type.

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