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RESEARCH ARTICLE

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DESIGN AND ANALYSIS OF EPOXY CARBON FIBER AUTOMOBILE LEAF SPRING

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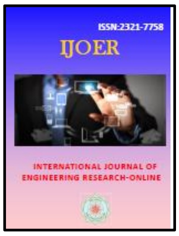

ABSTRACT
In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturers in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The suspension leaf spring is one of the potential items for weight reduction in automobiles as it accounts for 10% - 20% of the unstrung weight. This achieves the vehicle with more fuel efficiency and improved riding qualities.

1. INTRODUCTION

The use of fibre reinforced composites has become increasingly attractive alternative to the conventional metals for many mechanical components mainly due to their increased strength, durability, corrosion resistance, resistance to fatigue and damage tolerance characteristics. Composites also provide greater flexibility because the material can be tailored to meet the design requirements and they also offer significant weight advantages. Carefully designed individual composite parts, at present, are about 20-30% lighter than their conventional metal counterparts.

The most common fibres are carbon, aramid, glass and their hybrid. The resin matrix is generally an epoxy based system requiring curing temperatures between 120° and 180°C (250° and 350°F).

Types of FRC (Fiber reinforced composites)

The first structural composite components, which were introduced during 1950-60, were made from glass fibre reinforced plastics. These components included the fin and the rudder of Grumman E-2A, helicopter canopies, frames, radomes, fairings, rotor blades, etc. Due to high strength and stiffness combined with low density, composites like Boron Fibre Reinforced Plastics (BFRP) and Carbon Fibre Reinforced Plastics (CFRP) were preferred instead of aluminium for high performance.

For lightly loaded structures, Aramid Fibre Reinforced Plastics (AFRP) which possess low density, have been used. The use of AFRP continues to be restricted to the lightly loaded structures due to the fact that although these fibres possess high tensile strength, they have very low compressive strength. For lightly loaded structural components, Glass Fibre Reinforced Plastics (GFRP) has become one of the standard materials. Over the years, use of composite materials has also increased from few small access panels and canopy frames to almost complete airframe surfaces thereby providing weight savings leading to improved performance, reduced drag and also improved durability and corrosion resistance. Consequently, now-a-days, composite materials like GFRP, CFRP and AFRP have become standard materials for many applications.

The design considerations for leaf spring are impact resistance, stiffness and surface smoothness. We are using *epoxy glass fibre* for *leaf spring of light motor vehicle*.

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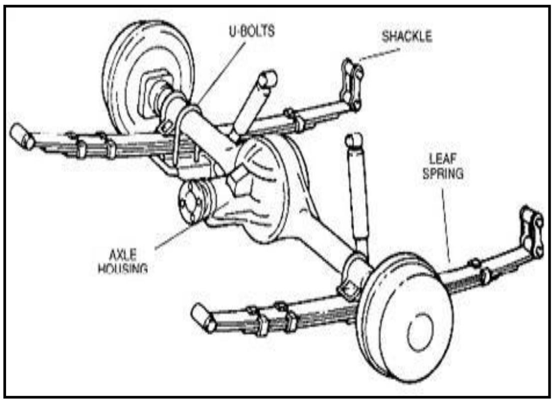
2 EXPERIMENTAL

2.1 Leaf Spring

A leaf spring is a straightforward type of spring regularly utilized for the suspension as a part of wheeled vehicles initially called a covered or carriage spring, and here and there alluded to as a semi – curved spring or truck spring or level plate.



Formulae for construction of leaf spring

Bending stress of leaf spring : $\sigma_b = \frac{6 \times W \times L}{n \times b \times t^2}$

Deflection of spring : $y = \frac{6 \times W \times L^3}{n \times E \times b \times t^2}$

$$Leaf thickness, h = \frac{\sigma_{des}\, L^2}{E\, \delta_{des}}$$

$$Leaf width, b = \frac{3FL}{\sigma_{des}\, h^2}$$

FORCE MOTORS TRAX CRUISER LEAF SPRING DETAILS:

Total length of the spring (Eye to Eye) = 1250 mm
No. of full length leaves (nf) = 02
No. of graduated leaves (ng)= 04
Thickness of leaf (t) = 7 mm
Width of the leaf spring (b) = 60 mm.
Young's modulus (E)= 2x10^5 N/mm^2
Central band width (Ineffective length)= 110 mm
Tensile strength ($t\,\sigma$) = 1900-2400 N/mm^2
Yield strength ($y\,\sigma$) = 1800 N/mm^2
Total load = 2850 Kg
BHN = 500 – 580 HB with hardened and tempered

FORCE MOTORS TRAX CRUISER LOAD

Maximum capacity = 2850 Kg
= 2850 x 10
= 28500 N

Force Motors Trax Cruiser is equipped with 4 nos. of semi elliptical leaf spring, So load acting on the leaf spring assembly =28500/4 = 7125 N

Calculation of leaf spring:

Load of leaf spring: Consider the leaf spring is cantilever beam. So the load acting on the each assembly of the leaf spring is acted on the two ends of the leaf spring. Load acted on the leaf spring is divided by the two because of consideration of the cantilever beam.

2∗W = 7125 N
W =7125/2
W = 3562.5 N

For support and clamping of the leaf spring the "U" bolt is use and the distance between the "U" bolt is 110 mm. This is considered as an unbent portion of the leaf spring.

Ineffective length of the leaf spring:

l = 110.00 mm

Effective Length of the spring,

2∗L = 2∗L –l
2∗L = 1250 –2/3 (110)
2∗L = 1176.67
L = 1176.67/2
L = 588.34 mm

Stresses generated in the leaf spring:

Material of the leaf spring is 50 Cr 1 V 23
Properties of the material:
Tensile strength ($\sigma\, t$) = 190 – 240 Kgf/mm^2
= 1900 – 2400 N/mm^2
Yield strength (σy) = 180 Kgf/mm^2
= 1800 N/mm^2

Modulus of elasticity (E) = 200000 N/mm^2
BHN = 500 – 580 HB with hardened and tempered by considering the factor of safety for the safety purpose of the leaf spring is 1.5 for automobile leaf spring.

Allowable stress:

Tensile strength (σt) = 1900/1.5 = 1266.66 N/mm^2

Yield strength (σy) = 1800/ 1.5 = 1200 N/mm^2

Bending stress:

Bending stress of leaf spring : $\sigma_b = \frac{6 \times W \times L}{n \times b \times t^2}$

(σb) = (6 x 3562.5 x 588.34) / (6 x 60 x 6^2)= 712.91 N / mm^2

So, the stress generated in the leaf spring is lower than the allowable design stress. So design is safe.

Deflection:

Deflection of spring : $y = \frac{6 \times W \times L^3}{n \times E \times b \times t^2}$

Y= (6 x 3562.5 x 588.34^3) / (6 x 2 x 10^5 x 60 x 7^3) = 176.26 mm

Pin Calculations: Allowable bearing pressure of the eye (p_b)

=8 N/mm2

Take length of the eye (l_1)

= 60 mm.

Load acting on the eye W

= d l p

$$d = \frac{W}{l_1 * p_b}$$

d = 3562.5 / (60 x 8)

=7.42 mm

= 8 mm

Bending moment of the pin:

Length of the pin = Length of the eye + (2 x Clearance)

(Take the clearance 2.50 mm per side)

l p = 60 + (2 x 2.50)

l p = 65 mm

Maximum bending moment acting on the pin:

M = (W x l_p) / 4

M = (3562.5 x 65) / 4

= 57890.62 N mm

Modulus of the section of the pin:

Z= (π x d ^{3}) / 32

=0.0982 x d^3

Bending stress on pin:

σb = M/ Z

=3562.5/0.0982 d^3

43= 3562.5/ 0.0982d^3

Considering bending stress 43.00 N/mm^2

d = 29.93

= 30mm

Shear stress in pin:

In assembly of the leaf spring pin acting under the double shear action due to assembly structure of the leaf spring.

$$W = 2 * \frac{\pi}{4} * d^2 * \tau$$

$$\tau = \frac{W * 4}{2 * \pi * d^2}$$

$$\tau = \frac{3562.5 * 4}{2 * \pi * (30)^2}$$

$$\tau = 2.52\ N/mm^2$$

Both the stresses, i.e, Tensile stress and shear stress are lower than the allowable stress. So design is safe.

The length of leaves:

Ineffective length of the leaf spring (l) = 110 mm

Length of the smallest leaf

$$= \left[\frac{2 \times l}{n-1} \times 1\right] + \frac{2}{3} \times (ineffective\ length)$$

$$= \left[\frac{2 \times 588.34}{6-1} \times 1\right] + 73.33$$

=308.66 mm

Length of the 2nd leaf

$$= \left[\frac{2 \times l}{n-1} \times 2\right] + \frac{2}{3} \times (ineffective\ length)$$

$$= \left[\frac{2 \times 588.34}{6-1} \times 2\right] + 73.33$$

=544 mm

Length of the 3rd leaf

$$= \left[\frac{2 \times l}{n-1} \times 3\right] + \frac{2}{3} \times (ineffective\ length)$$

$$= \left[\frac{2 \times 588.34}{6-1} \times 3\right] + 73.33$$

= 779.34 mm

Length of the 4th leaf

$$= \left[\frac{2 \times l}{n-1} \times 4\right] + \frac{2}{3} \times (ineffective\ length)$$

$$= \left[\frac{2 \times 588.34}{6-1} \times 4\right] + 73.33$$

= 1014.67mm

Length of the 5th leaf

$$= \left[\frac{2 \times l}{n-1} \times 5\right] + \frac{2}{3} \times (ineffective\ length)$$

$$= \left[\frac{2 \times 588.34}{6-1} \times 5\right] + 73.33$$

= 1250 mm

As per design 5th and 6th leaves are full length leaves and the 6th leaf is known as a master leaf.

Length of the master leaf:

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Length of master leaf $\lambda = 2 \times L_1 + \pi\,(d + t) \times 2$

$= \quad 1250 + \pi\,(30+7) \times 2$

$= \quad 1482.48$ mm

Radius:
R = Radius to which the leaves should be initially bent
y = Camber of the spring

$$y\,(2 \times R - y) = (L_1)^2$$

$176.26\,(2xR - 176.26) = (625)^2$

→ R=1196.22 mm

3. MODELING OF LEAF SPRING

AutoCAD Mechanical software includes all the functionality of AutoCAD software, plus comprehensive libraries of standards-based parts and tools for automating common mechanical drawing tasks. It is a very good and productive software that used for design of all types of engineering drawings. It is very easy to access and use.

Based on the dimensions obtained from the conventional design of leaf spring, the model of the leaf spring was created with the help of the 3-D modeling CAD software.

It is a very much easy to draw the engineering drawings with this Autocad by its user friendliness.

3.1 Procedure to model the leaf spring:

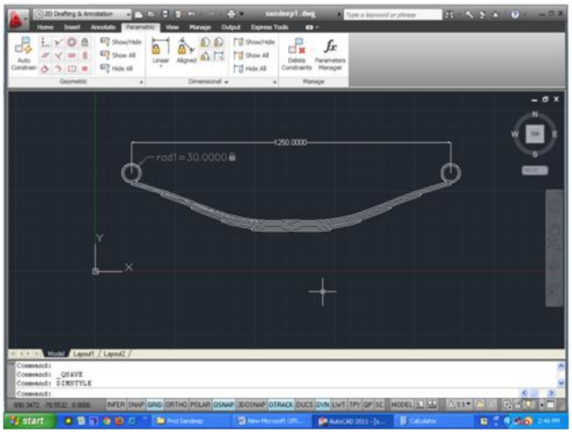
1) Taken a vertical and horizontal construction line for an imaginary center for drawing by using XLINE
2) Given OFFSET for the distance of L/2 of spring length on vertical center line
3) By this intersecting points drawn two circle with eye diameter
4) Used OFFSET command to get eye out side dia
5) Divided equal parts the horizontal and vertical line to get the intersection points to draw the SPLINE for leaf spring.
6) Drawn the main leaf spring and trimmed the unwanted all portion by TRIM.
7) Created region by REGION tool.
8) Then extruded the shape to 3D.
9) Saved it in dwfx format for uploading to ANSYS

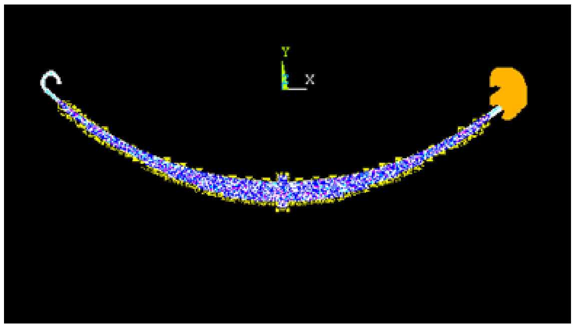
4 STEEL LEAF SPRING ANALYSIS

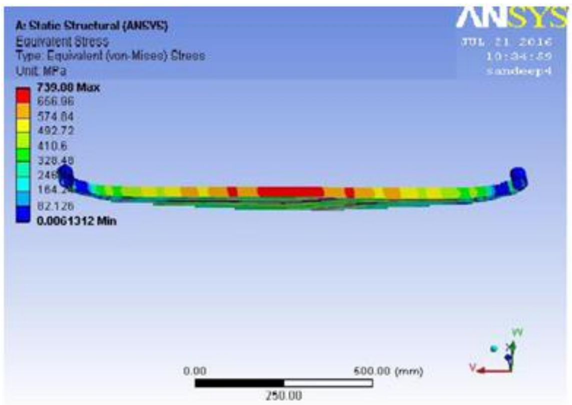
4.1 Properties of steel material

Table 4.1 Properties of steel

Properties of steel	
Material selected	50Cr1V23
Young's modulus	$2*10^5$ Mpa
Passion's ratio	0.3
BHN	534-601
Tensile strength ultimate	2000 Mpa
Tensile strength yield	1800 Mpa
Density	7850 Kg/m^3







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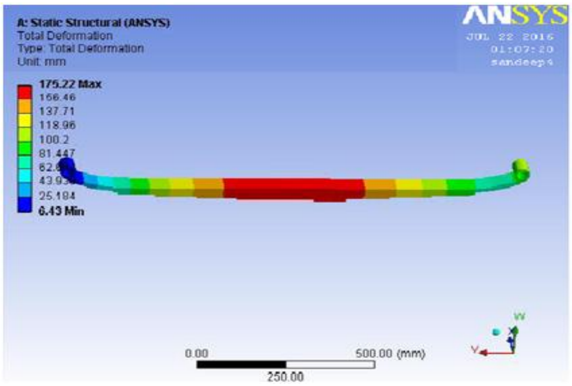

4.2 Result table for analytical and analysis of steel leaf spring

Below table shows that static analysis fairly matches with the analytical results but it also shows that static analytical results underestimate the results. For the optimization of leaf spring, accurate prediction of stress and deflection is necessary for that reason we have to perform model and transient analysis of leaf spring.

Table 4.2 Comparison Table for Analytical and ANSYS Results

Parameters	Analytical results	Static analysis results	Percentage variation
Von-mises stress (MPa)	712.91	739.08	3.54%
Maximum deflection (mm)	176.26	175.22	0.60%

5.0 Properties of Epoxy

Table 5.1 Properties of Epoxy material

S No.	Properties	E-glass/epoxy	Carbon epoxy	Graphite epoxy
1	EX (MPa)	43000	177000	294000
2	EY (MPa)	6500	10600	6400
3	EZ (MPa)	6500	10600	6400
4	PRXY	0.27	0.27	0.023
5	PRYZ	0.06	0.02	0.01
6	PRZX	0.06	0.02	0.01
7	GXY (MPa)	4500	7600	4900
8	GYZ (MPa)	2500	2500	3000
9	GZX (MPa)	2500	2500	3000
10	ρ (kg/mm³)	0.000002	1.6E-06	1.59E-06

EPOXY CARBON

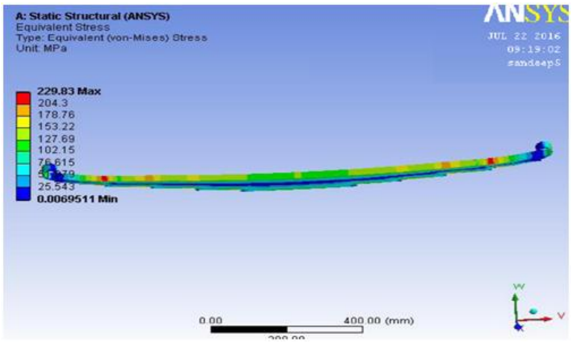

Fig.5.1 EPOXY CARBON VONMISES STRES

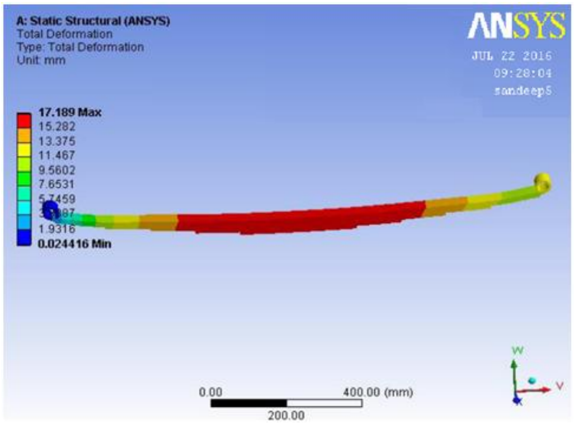

Fig. 5.2 EPOXY CARBON TOTAL DEFORMATION

EPOXY GRAPHITE

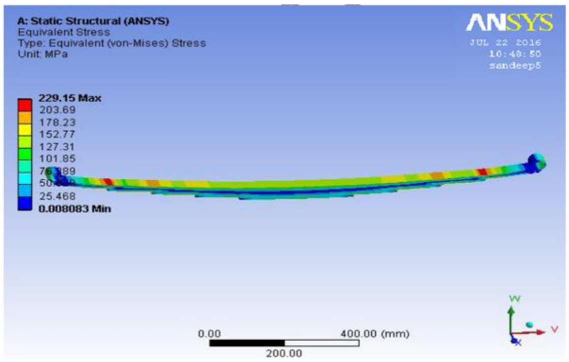

Fig. 5.3 EPOXY GRAPITE VON MISES

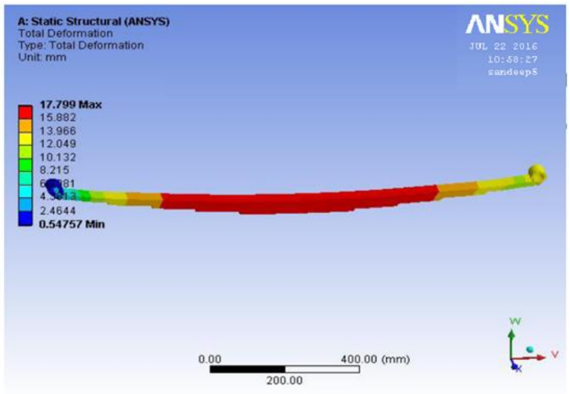

Fig.5.4 EPOXY GRAPHITE TOTAL DEFORMATION

5.2 COMPARISON OF STEEL LEAF SPRING WITH EPOXY FIBER LEAF SPRING ANALYSIS

Table 5.1 Comparison of analysis results of steel with Epoxy leaf springs

Material / Property	Steel	Epoxy Glass	Epoxy Carbon	Epoxy Graphite
Displacements (mm)	175.22	51.62	17.18	17.79
Stress (MPa)	739.08	237.49	229.83	229.15
Weight (Kg)	17.56	4.57	3.65	3.63

Here, from comparison of steel leaf spring with composite leaf spring as shown in table 5.1, it can be see that the maximum deflection 175.22 mm on steel leaf spring and corresponding deflection in E-glass/epoxy, Carbon epoxy and Graphite epoxy are 51.62 mm, 17.18 mm and 17.79 mm. Also the von-misses stress in the steel leaf spring 739.08 MPa while in Eglass/ epoxy, Carbon epoxy and Graphite epoxy the von-misses stress are 237.49 MPa, 229.83 MPa and 229.15 MPa respectively. 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 74.54% for E-glass/epoxy, 79.66% for Carbon epoxy and 79.77% for Graphite epoxy over steel leaf spring.

CONCLUSION

The design and static structural analysis of steel leaf spring and composite leaf spring has been carried out. Comparison has been made between composite leaf spring with steel leaf spring having same design and same load carrying capacity. The stress and displacements have been calculated using analytically as well as using ANSYS for steel leaf spring and composite leaf spring. From the static analysis results it is found that there is a maximum displacement of 175.22 mm in the steel leaf spring and the corresponding displacements in Eglass/ epoxy, Carbon epoxy and Graphite epoxy are 51.62 mm, 17.18 mm and 17.79 mm. From the static analysis results, it also seen that the von-mises stress in the steel leaf spring is 739.08 MPa and in E-glass/epoxy, Carbon epoxy and Graphite epoxy are 237.49 MPa, 229.83 MPa and 229.15 MPa respectively. All the three composite leaf springs have lower displacements and stresses than that of existing steel leaf spring.

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 74.54% for E-glass/epoxy, 79.66% for Carbon epoxy and 79.77% for Graphite epoxy over steel leaf spring.

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