Design and analysis of automobile leaf spring by changing cross sectional area and compared it with composite material

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Abstract

Leaf springs are one of the oldest suspension components they are still frequently used, especially in commercial vehicles. This work is carried out on a leaf spring of a TATA ACE EX. The automobile industry has shown increased interest in the replacement of steel spring with composite leaf spring due to high strength to weight ratio. This work deals with replacement of cross section of rectangular steel leaf spring of a light commercial vehicle with cross section of trapezoidal per leaf & whole shape as a tra pezoidal cross section of spring using 65si7. Numerical calculations are completed with the help of design equations of spring. Dimension of trapezoidal cross section per leaf & trapezoidal cross section are to be taken as same dimension of rectangular cross section of leaf. Different Material had been used for trapezoidal cross section per leaf & trapezoidal cross section & compare with each other .The modeling of the leaf spring have been done in PRO-E. Finite element analysis of the leaf spring have been carried out in ANSYS 14.5. Max Von Misses stress and Max Displacement are the output parameters of this analysis.

Keywords*- Steel Leaf spring, Different cross section, Composite leaf spring ,Static analysis*

I. INTRODUCTION

Today automotive manufacturers are faced with several complex challenges. In a highly competitive market, customers are demanding more for their money. Motorists wish cars that propose high performance, comfort, refinement, safety as well as increased vehicle customization [10]. The automotive industry is also faced with Governments who are consistently introducing legislation that demand improvements in fuel efficiency, reduced emissions, increased recycling and greater safety for both pedestrians and occupants.

1.1 Principle of Leaf Spring [3]

The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the unsprung weight. The introduction of composites helps in designing a better suspension system with better ride quality if it can be achieved without much increase in cost and decrease in quality and reliability. In the design of springs, strain energy becomes the major factor. The relationship of the specific strain energy can be expressed as [8]

$$U = \frac{\sigma^2}{\rho E} \tag{1.1}$$

Where σ the strength is ρ is the density and E is the Young's Modulus.

1.2 Material Selection

The material used directly affects the quantity of storable energy in the leaf spring[1]. In general terms higher alloy content is mandatory to ensure adequate harden ability when the thick leaf sections are used. Plain carbon steel, Chromium vanadium steel, Chromium- Nickel- Molybdenum steel, Silicon-manganese steel, are the typical materials that are used in the design of leaf springs. The material used for this work is 65Si7.

Compared to carbon fibers, glass fibers have lower strength and stiffness, higher density, better corrosion resistance, higher impact strength and lower cost [1]. A good combination between the material properties and the cost is obtained with the glass fibers[1]. So in the present work the E-glass/epoxy is selected as the spring material.

Table-1.2 Mechanical properties of existing leaf spring [9].

Parameters	Value
Material of Spring	65Si7
Young's Modulus, E	2.1×10^{5} MPa
Poisson's Ratio,	0.266
Tensile Strength Ultimate	1272 MPa
Yield Strength	1158 MPa
Density	7.86×10^{6} Kg/mm^3

Table 1.3 mechanical property of material[10]

Property	Value
Material for spring	E-glass/Epoxy
Tensile strength of the material (Mpa)	900
Compressive strength of the material(Mpa)	450
Poisson ratio	0.3
Shear modulus	2433
Bulk modulus	91667
Young's Modulus MPa	$2.1*10^{5}$
Density	1608 kg/ mm^3

1.3 Problems Identification

After reviewing the literatures, we identify some of the problem which generally occurs in case of leaf spring. The usual steel leaf spring has various problems identified which are listed as follow:

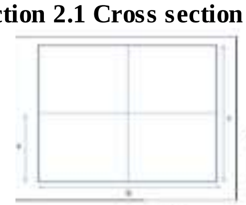
- Low strength: It is observed that the leaf springs be likely to break and deteriorate at the eye end segment which is extremely near to the shackle and at the middle.
- More weight: The usual steel leaf spring having more weight, which additionally influences the fuel efficiency.
- Higher Stress: The steel leaf spring generated higher stress & maximum deformation due to continuous running of the vehicle.
  For overcome the above problem steel leaf spring is replaced with composite leaf spring.

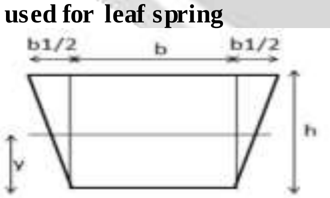
1.4 Objective

The objective of the present work is to design, analysis & optimization of leaf spring. Reducing weight while increasing or maintaining strength of products is getting to be highly important research issue in this modern world. This is done to achieve the following.

- To the replace conventional steel leaf spring rectangular cross section with steel leaf spring trapezoidal cross section per leaf & whole leaf spring shape as a trapezoidal cross section by using same dimensions for all three cross sections.
- To achieve substantial weight reduction in the suspension system by replacing all three cross section of leaf spring with composite leaf spring cross section.
- Find optimum cross section for leaf spring based on weight reduction & output parameters of leaf spring.
- Compare the load carrying capacity, stresses, deflection and weight savings of composite leaf spring for all cross section with that of cross section of steel leaf spring.

II. Design of leaf spring for cross section 2.1 Cross section used for leaf spring





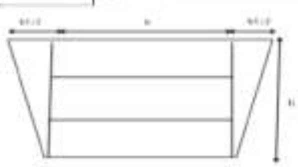


Figure 2.1 Rectangular cross section Figure 2.2 Trapezoidal cross section Figure 2.3 Trapezoidal cross section

2 .2 Dimensions Taken From Tata Ace Ex:

Table-2.1 Geometric properties of leaf spring for Rectangular cross section

Design parameter of leaf spring	Value
Number of extra full-length leaves(n_f)	3
Number of graduated leaves(n_g)	0
Total number of leaves	3
Width of each leaf	60mm
Thickness of each leaf	8mm
Span length	860mm
Force applied at the end of the spring	4941N
Half length	405mm

2.3 Design Equation for Rectangular Cross Section For Leaf Spring.

The equation of bending stress of spring is given by [12],

$$\sigma = \frac{18 * P * L}{b * t^3 (2n_g + 3n_f)} \quad (2.1)$$

The equation of Deflection of spring is given by [12],

$$\delta = \frac{(12 * P * L^3)}{(E * b * t^3 * (2 * ng + 3 * nf))} \quad (2.2)$$

2.3.1 Modification in cross section design.

Table 2.2 theoretical calculation of trapezoidal cross section

Cross section	Stress (MPa)	Deflection (mm)
60/40	723.39	47.36
60/50	605.35	40.72
60/55	559.00	37.24

From above results it is found that, by using cross-section 60/40 & 60/50 the value of stress is more than rectangular cross section .But by using 60/55 its found that value of stress & displacement is nearer to rectangular cross section . It also found from result that as value of width increased its result in decreasing value of stress & deflection. So proper cross section for leaf spring is selected 60/55.

2.4 Design Equation for Trapezoidal Per Leaf Cross Section for Leaf Spring.

The equation of bending stress of spring is,

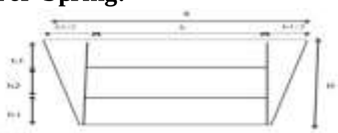
$$\sigma_b = \frac{36 * P * L(3 * b + 2 * b_1)}{h^2 (6 * b^2 + 6 * b * b_1 + b_1^2) * (3 * n_f + 2 * n_g)} \quad (2.3)$$

The equation of deflection of spring is,

$$\delta = \frac{36 \cdot P \cdot L^3 (2 \cdot b + b_1)}{E \cdot h^3 (6 \cdot b^2 + 6 \cdot b \cdot b_1 + b_1{}^2) + (2 \cdot n_g + 3 n_f)}$$

(2.4)

2.5 Design Calculation For Whole Shape As Trapezoidal Cross Section For Spring.



$$\frac{B-b}{H} = \frac{B-X}{h}$$

(2.5)

From equation (2.5), (2.3) & (2.4), we can find out the value for b, σ_1 & δ for each leaf.

Table 2.3 calculation for each leaf

Leaf	Value of b_1	Stress (Mpa)	Deflection (mm)
1st leaf	2.5	1677	113.00
2nd leaf	2.2	1682	114.63
3rd leaf	1.6	1688	114.87

III. STATIC ANALYSIS

3.1Boundary condition for analysis

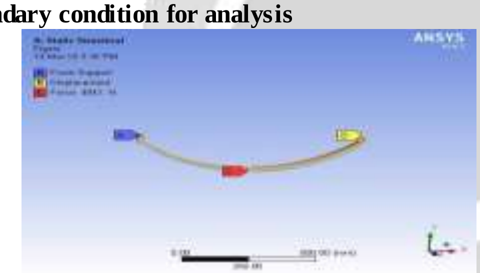
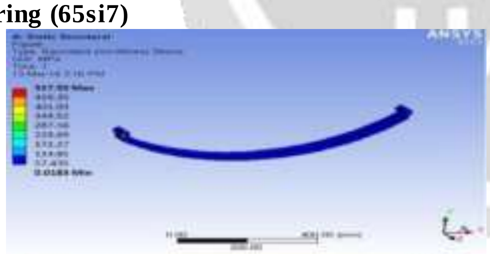


Figure 3.1 Boundary condition for leaf spring

3.2 Output for Leaf Spring

3.2.1 Output For Rectangular Cross Section For Leaf Spring (65si7)



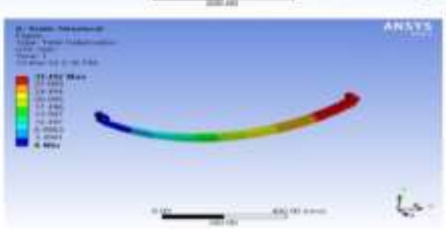
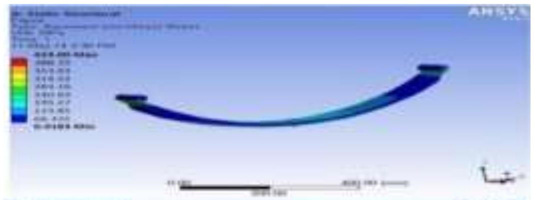


Figure 3.2 Von misses stress generated on spring Figure 3.3 Deflection generated on spring

3.2.2 Output for rectangular cross section for leaf spring (E-glass/Epoxy)



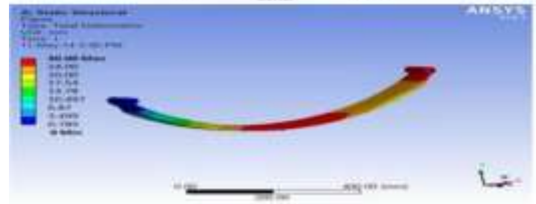
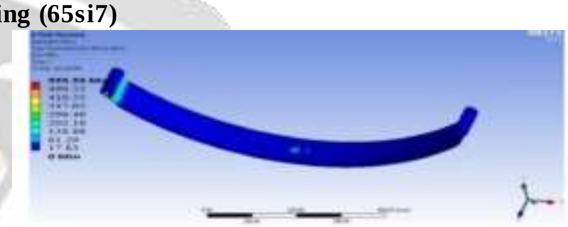


Figure 3.4 Von misses stress generated on spring Figure 3.5 Deflection generated on spring

3.2.3 Output for Trapezoidal cross section for leaf spring (65si7)



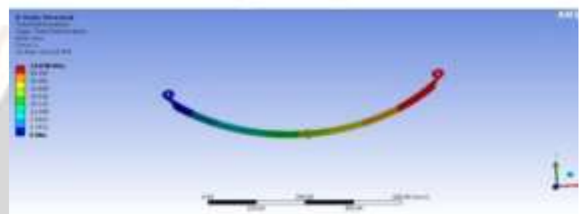
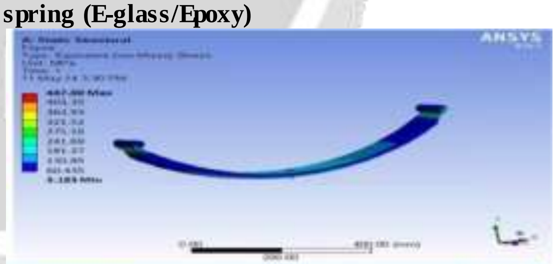


Figure 3.5 Von misses stress generated on spring Figure 3.6 Deflection generated on spring

3.2.4 Output for Trapezoidal cross section for leaf spring (E-glass/Epoxy)



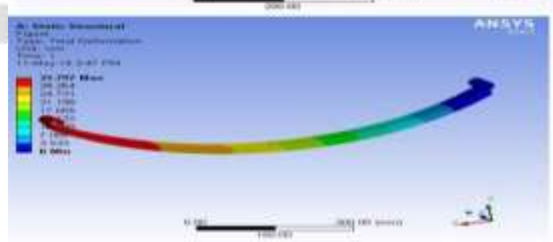
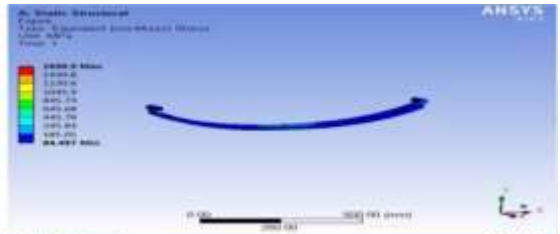


Figure 3.7 Von misses stress generated on spring Figure 3.8 Deflection generated on spring

3.3.5 Output for Trapezoidal cross section for leaf spring (65si7)



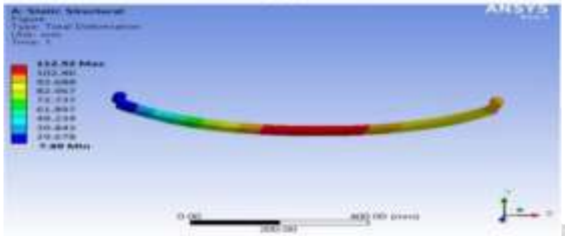
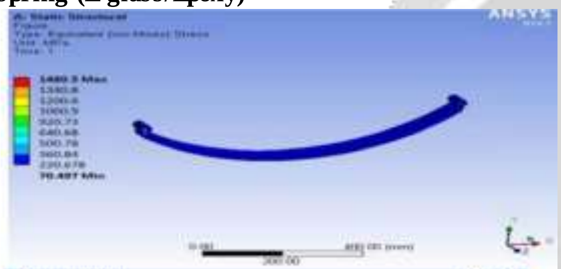


Figure 3.9 Von misses stress generated on spring Figure 3.10 Deflection generated on spring

3.3.6 Output for Trapezoidal cross section for leaf spring (E-glass/Epoxy)



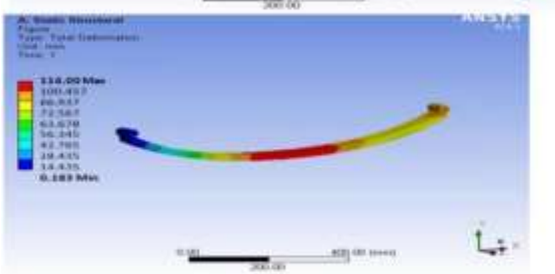


Figure 3.11 Von misses stress generated on spring Figure 3.12 Deflection generated on spring

IV. RESULTS & DISCUSSION

Table 4.1 Comparison of theoretical result with software for cross section

Cross section	Stress (Mpa)		Deflection (mm)		Variation		Weight of leaf(Kg)
	Analytical	ANSYS	Analytical	ANSYS	Stress	Deflection	
Rectangular	521.015	517.0	35.60	31.492	7.67%	11%	11.700
Trapezoidal per leaf	559.00	555.77	37.24	34.492	7.15%	8.7%	10.200
Trapezoidal as whole leaf	1682.33	1630.5	114.363	112.00	30%	1.75%	10.743

Table 4.2 Weight comparison between steel & composite for cross sections

Cross sections	Weight of 65Si7 (kg)	
Rectangular	11.00	
Trapezoidal per leaf	10.200	
Trapezoidal as whole leaf	10.742	

From the above table 4.1 it was observed that by using rectangular cross section the value of stress from software is 517.00 Mpa whereas by using trapezoidal per leaf cross section the value of stress is 555.77 Mpa & by using whole shape as a trapezoidal the value of stress is 1682.33 Mpa. So among three cross sections by using trapezoidal per leaf (65Si7), the value of output parameter results are nearer rectangular cross section & with in limit .The FEA results are compared with the theoretical result.

From the static analysis by using steel weight of rectangular cross section is 11.00 kg & by using steel weight of trapezoidal cross section per leaf is 10.200 kg .So from result it s found that by using trapezoidal cross section per leaf weight is reduced by 7.67% but by using composite its reduced by 11.244% . Maximum weight reduced by 63.62% using composite material for trapezoidal cross section per leaf.

Material	Rectangular		Trapezoidal per leaf		Trapezoidal whole shape	
	Stress	Deflection	Stress	Deflection	Stress	Deflection
Material (65si7)	517.55	31.492	555.55	34.492	1682.33	112.00
Material (E - glass/Epoxy)	423	30.00	447	31.00	1480.5	114.00
Reduction by E-glass epoxy	18.00%	3.00 %	19.45%	8.88 %	120.00%	17.00%

Table 5.2 Comparison of steel & composite material

V. CONCLUSION

- From the static analysis results it is found that there is a maximum von misses stress of 517.00 Mpa in the steel leaf spring for rectangular cross section of leaf and the corresponding von mosses stress in Trapezoidal cross section per leaf, Whole shape as a trapezoidal cross section of leaf are 555.77 Mpa, 1682 Mpa for a given load of 4941N.
- From static analysis it's found that by using composite material maximum von mises stress of 423.00 Mpa in the steel leaf spring for rectangular cross section of leaf and the corresponding von mosses stress in Trapezoidal cross section per leaf, Whole shape as a trapezoidal cross section of leaf are 447 Mpa, 1480.5 Mpa for a given load of 4941N. By using E-glass/epoxy it's observed that stresses are reduced rather than using steel material.
- 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.
- From static analysis it is observed that by using trapezoidal cross- section the material is reduced rather than by using rectangular cross section. It s found that by using trapezoidal cross section per leaf of steel, weight is reduced by 7.67% but by using composite material its reduced by 11.244% .Comparative study between cross sections & materials From analysis it is observed that weight of rectangular cross section by using steel is 11.00 kg & corresponding weight in Trapezoidal cross section per leaf is 10.200 kg & whole shape as trapezoidal 10.743 kg. But by using composite (E-glass/Epoxy) weight of rectangular cross section 4.55 Kg, corresponding weight in Trapezoidal cross section per leaf 3.71 kg & whole shape as trapezoidal 3.97 kg. Maximum weight is reduced by 63.62% using composite material for trapezoidal cross section per leaf. So trapezoidal per leaf .is selected as best cross section for leaf based on weight.
- From static analysis in whole shape as a trapezoidal cross section value of stress is 1682Mpa & deflection is 112.00 mm. So Whole shape as a trapezoidal cross section of leaf is not proper for leaf spring due to stress & deflection of leaf spring are out of limit of material capacity & not within safety factor.

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