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Design, Analysis and Experimental Investigation of Composite Leaf Spring

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ABSTRACT

Leaf spring is part of suspension system used in most of vehicles and makes the vehicle heavier due to conventional steel material. The Automobile industry has concentrated and given former interest to substitute that conventional materials like steel in replace with other material due to various reasons like different mechanical properties. Lot of research has been going on to replace leaf spring with Composite materials. Composite materials are satisfying various demands of automobile researchers as it having good elastic properties, high strength to weight ratio, less weight compared to steel material. The aim of this paper is to focus on various issues like weight, stresses while designing, modeling and experimental investigation of composite leaf spring. In the present work stress and deflection analysis of leaf spring are calculated by finite element analysis. The leaf springs are analyzed in ANSYS 14.5 for stresses and deflections. The results shows from different calculations and data observed that, for the similar load carrying capacity induced stresses and deflections get minimized when steel leaf spring is replaced by fibrous composite (E-Glass/epoxy) leaves. The analysis was carried by considering model of Force Motors Trax Cruiser's leaf spring with same dimensional geometry, for reduction in weight of leaf spring. E-glass/epoxy composite material is selected for leaf spring, which is more cost effective with same mechanical and dimensional properties of steel leaf spring. The analysis was carried out on ANSYS 14.5 with same loading condition for deflection and bending stress of steel as well as E-glass/epoxy composite material. A comparative study has been made between steel and composite leaf spring with respect to strength and weight. From the static analysis and experimental results it is found composite leaf springs have lesser displacements and stresses than that of conventional steel leaf spring. The weight of the leaf spring is minimized extremely about 71.73 % and 50 to 80 % reduction in stresses after replacing steel leaf spring with composite leaf spring.

Keywords: Leaf Spring, Steel Material, Weight Reduction, Composite Material: E-Glass/Epoxy.

I. INTRODUCTION

Leaf Spring

Nowadays, Better fuel efficiency, emission issues and reducing weight are become main focus area in automobile sector. In that issue, weight reduction can be done by implementing better material, optimizing an appropriate design & quality manufacturing. In automobile sector, Leaf spring is used as suspension in most of vehicles. So reducing weight of leaf spring get beneficial and can help to achieve the objective as per demands. For better material, composites are get closure to achieve weight reduction without any change in load carrying capacity, stiffness parameters. Composite materials are having good elastic strain energy, good strength to weight ratio, less weight than steel leaf spring.

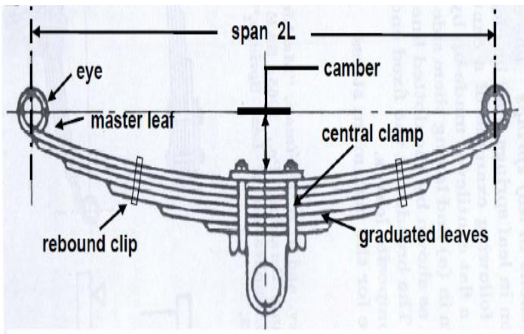


Figure 1: Multi-Leaf Spring

Figure 2 : Steel Leaf Spring used in Vehicles (e.g. used in trucks)

II. METHODS AND MATERIAL

1. Why A Composite Material for Leaf Spring?

From last thirty years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have developed steadily, penetrating and conquering new markets continuously. Modern composite materials constitute a significant proportion of the engineering materials market ranging from everyday products to sophisticated niche applications. While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry. It is acceptable, particularly for composites, that to produce new technology in manufacturing technology is not enough to overcome the cost obstacle. It is essential that there be an integrated effort in design, material, process, tooling quality assurance, manufacturing, and even program management for composites to become competitive with metals. Further, the need of composite for lighter construction materials and more seismic resistant structures has placed high emphasis on the use of new and advanced materials that not only decreases dead weight but also absorbs the shock & vibration. Composites are now extensively being used for rehabilitation/ strengthening of pre-existing structures that have to be retrofitted to make them seismic resistant, or to repair damage caused by seismic activity.

Unlike conventional materials (e.g. steel), the properties of the composite material can be accomplished by considering the structural relevance. Both material and structural design involves while design of a structural component using composite materials. Composite properties (e.g. stiffness,) can be differed continuously over a lot range of values under the control of the modifier. Careful selection of reinforcement type allows finished product characteristics to be bespoke to almost any specific engineering necessity. While the use of composites will be a only better choice in many criterion, material selection in others will depend on factors such as working lifetime needs, number of items to be produced, complexity of product shape, possible savings in product costs and on the experience & skills the designer in tapping the optimum value of composites. In some instances, best results may be achieved through the use of composites in combination with traditional materials.

2. Objective of the Study

The following are the objectives of the study:

1) Study existing leaf spring and its design. Geometric modelling of existing leaf spring.
2) To carry out linear static analysis of existing leaf spring.
3) To carry out analysis of leaf spring design for similar loading condition.
4) To carry out experimental validation with obtained results.
5) Recommendation of new solution for weight optimization.

3. Proposed Flow of Work

1) To develop a covering model suitable for linear static analysis.
2) To generate a finite element model of the same.
3) To carry out all the necessary checks on the model.
4) To carry out the linear analysis to study the behaviour.
5) To validate the model for the limiting load (permissible load).

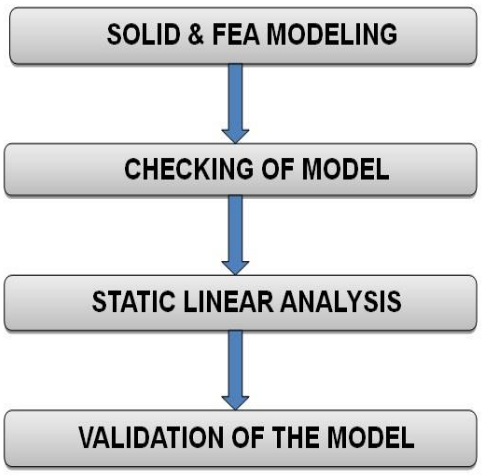


Figure 3 : Project flow work

4. Methodology

1) 3D modelling of leaf spring as per dimension.
2) Analysis of leaf spring in ANSYS 14.5 for static loading condition.
3) For weight optimization we use Glass Fiber (GF) as a composite material for leaf spring.
4) Design of leaf spring for composite material by using analytical calculation.
5) 3D model of leaf spring as per result of hand calculation.
6) Analysis of leaf spring in ANSYS 14.5 for static loading condition.
7) If all result are OK then go for manufacturing, if not then again design and analysis by using ANSYS 14.5.
8) After manufacturing, observe result by using UTM for stresses & deflection in leaf spring.

5. Design Calculation of Leaf Spring

Basic data of leaf spring:-

- Material selected steel: 50 Cr 1 V 23
- Total length of the spring (Eye to Eye) = 1250 mm
- No. of full length leaves (n_f) = 02
- No. of graduated leaves (n_g) = 04
- Thickness of leaf (t) = 7 mm
- Width of the leaf spring (b) = 60 mm
- Young's modulus (E) = 2x105 N/mm2
- Central band 110 mm wide (Ineffective length)
- Tensile strength (σ_t) = 1900-2400 N/mm2
- Yield strength (σ_y) = 1800 N/mm2
- Total load = 2850 Kg
- BHN = 500 – 580 HB with hardened and tempered
- Basic requirement of load:

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

- Load acting on the leaf spring assembly = $\frac{28500}{4}$ = 7125N
- Bending stress generated in the leaf spring is as under:

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

- Deflection generated in the assembly of leaf spring is as under:

$$y = \frac{12*W*L^3}{E*b*t^3(2n_g+3n_f)}$$

- In this way, design of leaf spring was done as shown in following table

TABLE I : DESIGN CALCULATION OF LEAF SPRING AT DIFFERENT LOADING CONDITION

Sr. No.	Load applied on conventional leaf spring(N)			Bending Stress (σ_b) Occurred in (MPa)	Deflection (y) occurred in (mm)
	Total Load	Central Load (2 W)	(W)		
1.	30000	7500	3750	750.43	159.03
2.	28500	7125	3562.5	712.91	151.08
3.	25000	6250	3125	625.36	132.52
4.	20000	5000	2500	500.28	106.02
5.	15000	3750	1875	375.21	79.51
6.	10000	2500	1250	250.14	53.01
7.	5000	1250	625	125.07	26.50

6. Material Selection Design

TABLE II : PROPERTIES OF STEEL LEAF SPRING (50CR1V23)

Sr. no	Properties		Steel
1	YOUNG MODULUS (E)	EX(MPa)	200000 MPa
2	POISSONS RATIO	PRXY	0.3
3	SHEAR MODULUS (G)	GX (MPa)	76923 MPa
4	DENSITY	ρ (kg/m³)	0.000007850

TABLE III PROPERTIES OF COMPOSITE SPRING (E-GLASS/EPOXY)

Sr. no	**Properties**		**E-glass/epoxy**
1	YOUNG MODULUS(E)	E_X(MPa)	43000
		E_Y(MPa)	6500
		E_Z(MPa)	6500
2	POISSONS RATIO	PR_{XY}	0.27
		PR_{YZ}	0.06
		PR_{ZX}	0.06
3	SHEAR MODULUS (G)	G_X(MPa)	4500
		G_Y(MPa)	2500
		G_Z(MPa)	2500
4	DENSITY	ρ (kg/mm³)	0.000002

7. Modelling And Analysis of Steel Leaf Spring

A. Modelling of Steel leaf spring in Auto-CAD:

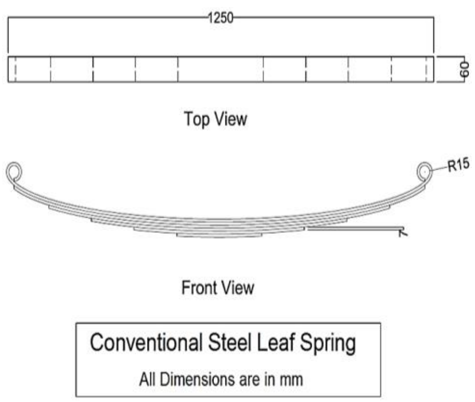


Figure 4 : Drawing of Steel leaf spring in Auto-CAD

B. 3D modelling of Steel leaf spring in ANSYS 14.5:

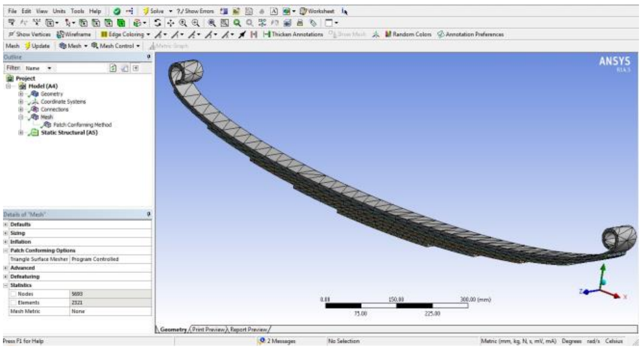


Figure 5 : 3D Modelling of Steel leaf spring (Meshed body)

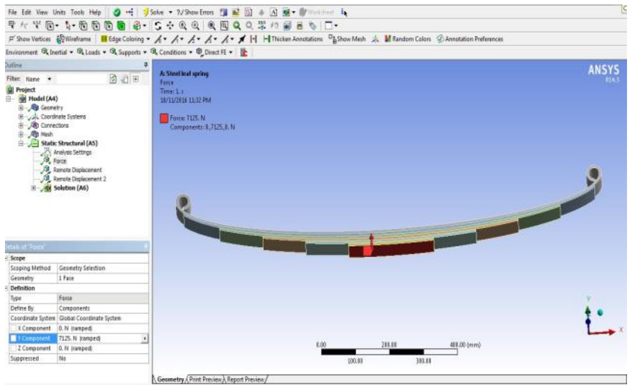


Figure 6 : 3D Modelling of Steel leaf spring (Defining Force)

C. FEA-Result Analysis Of Steel Leaf Spring

- Application of Load on spring = 3 ton=30000N

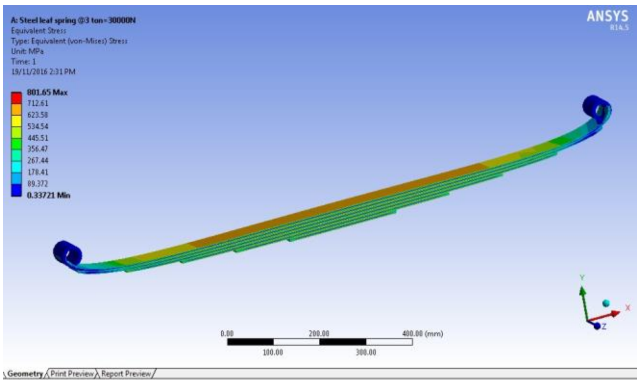


Figure 7 : Equivalent (Von-mises) stress contour of steel leaf spring at 30000N.

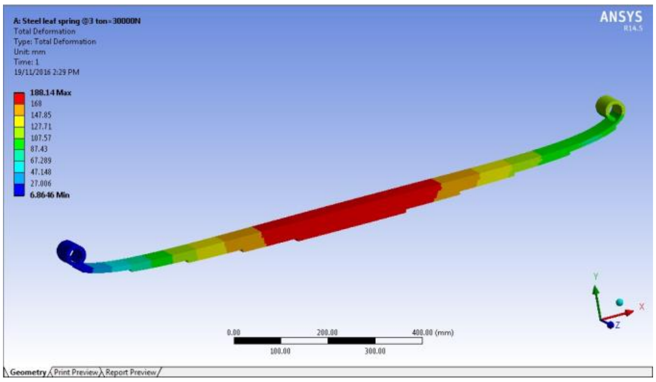


Figure 8 : Maximum deflection contour of steel leaf spring at 30000N.

TABLE-IV RESULTS ON VARIOUS LOADING CONDITIONS-(FOR STEEL LEAF SPRING)

Sr. No	Load applied on conventional leaf spring (N)			Bending Stress (σ_b) Occurred in (MPa)	Deflection (y) occurred in (mm)
	Total Load	Central Load			
		(2W)	(W)		
1)	30000	7500	3750	801.65	188.14
2)	28500	7125	3562.5	761.56	178.73
3)	25000	6250	3125	668.04	156.78
4)	20000	5000	2500	534.43	125.43
5)	15000	3750	1875	400.82	94.06
6)	10000	2500	1250	267.22	62.71
7)	5000	1250	625	133.61	31.35

TABLE-V WEIGHT OF STEEL LEAF SPRING OBSERVED IN ANSYS

Sr. No.	Material of Leaf spring	Weight observed in ANSYS
1)	Conventional Steel Leaf spring	16.28

8. Modelling And Analysis of Composite Leaf Spring

A. Modeling of Composite Leaf spring in Auto-CAD:

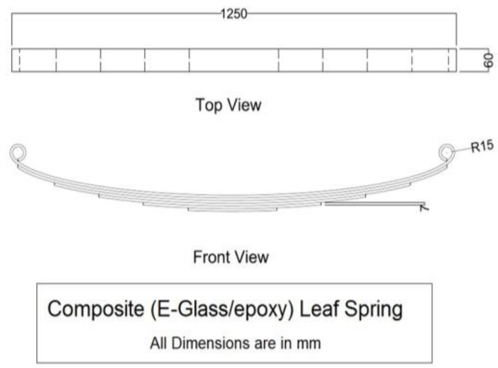


Figure 9 : Drawing of Composite leaf spring in Auto-CAD

B. 3D Modeling of Composite leaf spring in ANSYS 14.5:

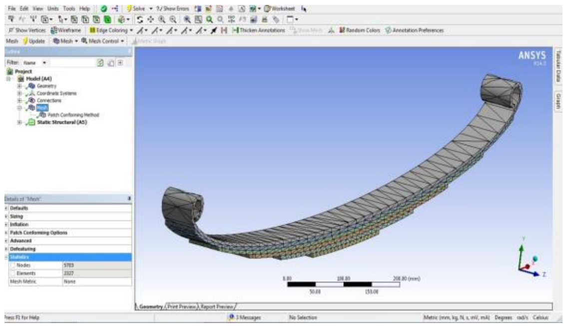


Figure 10 : 3D Modeling of Composite leaf spring (Meshed body)

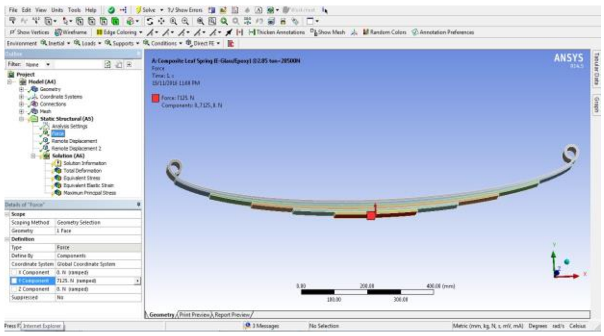


Figure 11 : 3D Modeling of Composite leaf spring (Defining Force)

C. FEA-Result Analysis Of Composite Leaf Spring

- Application of Load on spring = 3 ton=30000N

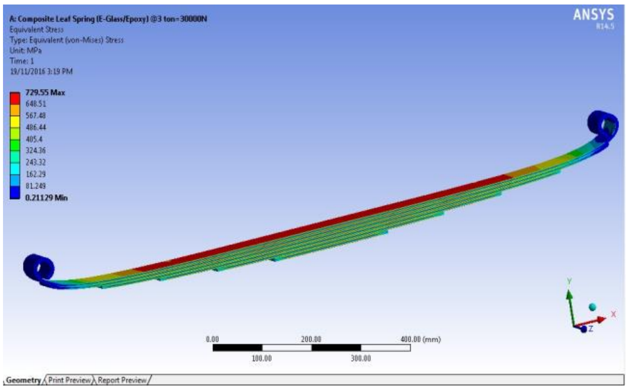


Figure 12 : Equivalent (Von-mises) stress contour of composite leaf spring at 30000N.

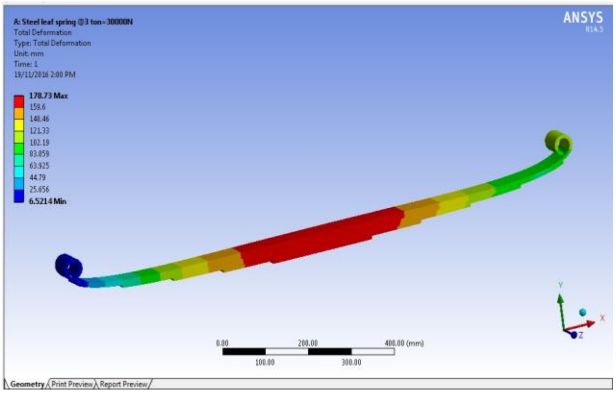


Figure 13 : Maximum deflection contour of composite leaf spring at 30000N.

TABLE-VI RESULTS ON VARIOUS LOADING ONDITIONS-(FOR COMPOSITE LEAF SPRING)

Sr. No.	Load applied on composite leaf spring (N)			Bending Stress (σ_b) Occurred in (MPa)	Deflection (y) occurred in (mm)
	Total Load	Central Load			
		(2W)	(W)		
1)	30000	7500	3750	729.55	981.54
2)	28500	7125	3562.5	693.07	932.47
3)	25000	6250	3125	607.96	817.95
4)	20000	5000	2500	486.37	654.36
5)	15000	3750	1875	364.78	490.77
6)	10000	2500	1250	243.18	327.18
7)	5000	1250	625	121.59	163.59

D. Comparison Results For Steel And Composite Leaf Spring

TABLE-VII COMPARISON RESULTS OF VON-MISES STRESS FOR STEEL AND COMPOSITE LEAF SPRING

Sr. No.	LOAD (N)	VON-MISES STRESS (MPa)		
		Design calculation Results for Steel Leaf Spring	FEA Results for Steel Leaf Spring	FEA Results for Composite Leaf Spring
1)	30000	750.43	801.65	729.55
2)	28500	712.91	761.56	693.07
3)	25000	625.36	668.04	607.96
4)	20000	500.28	534.43	486.37
5)	15000	375.21	400.82	364.78
6)	10000	250.14	267.22	243.18
7)	5000	125.07	133.61	121.59

TABLE-VIII COMPARISON RESULTS OF DEFLECTION FOR STEEL AND COMPOSITE LEAF SPRING

Sr. No.	LOAD (N)	DEFLECTIONS (mm)		
		Design calculation Results for Steel Leaf Spring	FEA Results for Steel Leaf Spring	FEA Results for Composite Leaf Spring
1)	30000	159.03	188.14	981.54
2)	28500	151.08	178.73	932.47
3)	25000	132.52	156.78	817.95
4)	20000	106.02	125.43	654.36
5)	15000	79.51	94.06	490.77
6)	10000	53.01	62.71	327.18
7)	5000	26.50	31.35	163.59

TABLE-IX WEIGHT OF COMPOSITE LEAF SPRING OBSERVED IN ANSYS:-

Sr. No.	Material of Leaf spring	Weight observed in ANSYS
1)	Composite Leaf spring	4.0836 Kg

9. Experimental Investigation and Validation

A. Introduction to Testing

For experiments, the existing leaf spring designed by the Sponsoring firm for vendors is put to test. The leaf spring would normally encounter gradually applied loads. For reasons of safety, `sudden load' is already considered during its design phase. As such, the existing steel leaf spring is tested for mechanical strength, while a trial is taken. For trials, Leaf spring is grouted in the floor with nuts and bolts as has been designed for the full scale implementation. A minimum of 30 nos. passes of the component from end to end are carried during the experimentation phase.

Figure 14 (A): Universal Testing Machine

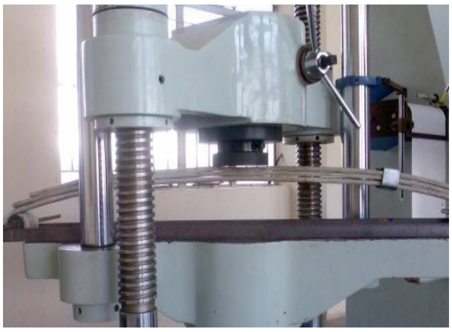


Figure 14 (B) Composite Leaf Spring under loading condition on Universal Testing Machine

B. Validation

Upon completion of the experimentation, the assembly is observed for any visible damage to the leaf spring. The units are measured for their height, especially at the central region along the length of the unit with a general purpose retractable measuring tape. The recorded measurement does not highlighting any sag induced in the unit during the experimentation phase.

TABLE-X EXPERIMENTAL RESULTS FOR DEFLECTION AT VARIOUS LOADS ON UTM MACHINE (FOR CONVENTIONAL STEEL LEAF SPRING):-

Sr. No.	Load applied on Conventional leaf spring (N)			Deflection (*y*) occurred in (mm)
	Total Load	Central Load (2W)	Central Load (W)	
1)	30000	7500	3750	178
2)	28500	7125	3562.5	168.3
3)	25000	6250	3125	148
4)	20000	5000	2500	120.5
5)	15000	3750	1875	78
6)	10000	2500	1250	60
7)	5000	1250	625	35.8

TABLE-XI EXPERIMENTAL RESULTS FOR DEFLECTION AT VARIOUS LOADS ON UTM MACHINE (FOR COMPOSITE STEEL LEAF SPRING):-

Sr. No.	Load applied on Composite leaf spring (N)			Deflection (*y*) occurred in (mm)
	Total Load	Central Load (2W)	Central Load (W)	
1	30000	7500	3750	955.4
2)	28500	7125	3562.5	920.2
3)	25000	6250	3125	835
4)	20000	5000	2500	660.8
5)	15000	3750	1875	498
6)	10000	2500	1250	332.7
7)	5000	1250	625	142

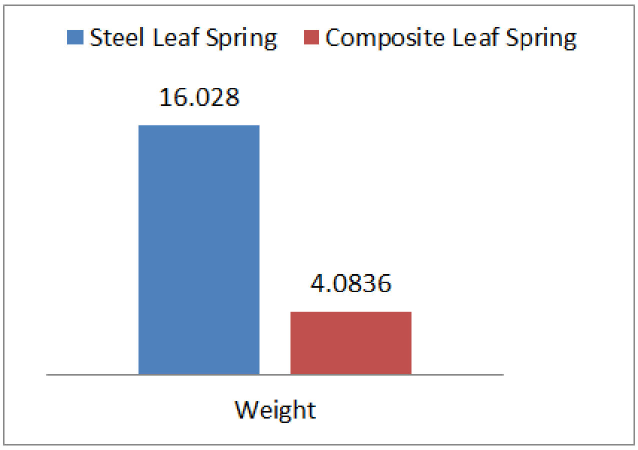
III. RESULTS AND DISCUSSION

TABLE XII : - WEIGHT REDUCTION DUE TO OPTIMIZATION-ANALYTICALLY

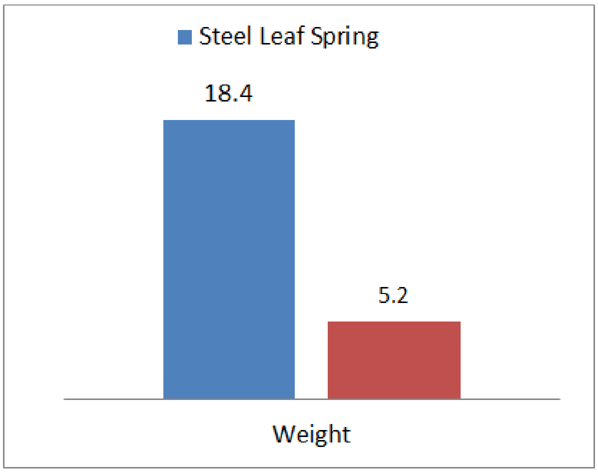
Design	Weight (Kg) (Analytically)	% Material required compared to existing design	% Material save compared to existing design
Existing(Steel)	16.028	100	------------------
Optimized (Composite Material)	4.0836	25.48	74.52

TABLE XIII : - WEIGHT REDUCTION DUE TO OPTIMIZATION-EXPERIMENTALLY

Design	Weight (Kg) (Analytically)	% Material required compared to existing design	% Material save compared to existing design
Existing(Steel)	18.400	100	------------------
Optimized (Composite Material)	5.200	28.27	71.73



(A)



(B)

Figure 15 : Comparison of weights in steel Leaf Spring and composite Leaf spring-(a) Analytically (b) Experimentally

IV. CONCLUSION

The composite leaf spring is lighter than conventional steel leaf spring with similar design specifications but not always is cost- effective over their steel counterparts. Composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel. Therefore, it is concluded that composite leaf spring is an effective replacement for the existing steel leaf spring in automobile.

- E-glass epoxy is better than using Mild-steel as however stresses are little bit greater than mild steel, E-glass epoxy is having good yield strength worth.
- The weight of the leaf spring is reduced considerably about 71.73 % by replacing steel leaf spring with composite leaf spring. Thus, the objective of reducing the unstrung mass.
- 11.9444 Kg weight reduction achieved by optimized design than existing design.
- 50 - 80 % reduction in stresses.
- Actual physical model is done for validation using optimized design parameters and it is found that the design is safe.

This project is very beneficial for reducing the overall all weight of Leaf spring. By changing a material the weight of system is reduced but the deformation is increased. But, there is no effect of it on overall all system. The Leaf spring is checked on UTM and is observed that the system is safe .by plotting graph of load v/s deflection. The graph of existing system is giving suddenly increased deflection in load range of 5000 to 30000 but the graph for optimized Leaf spring is smoothly increased at all loads.

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