DESIGN AND STATIC ANALYSIS OF COMPOSITE LEAF SPRING

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ABSTRACT

Leaf springs are one of the oldest suspension components they are still frequently used, especially in commercial vehicles. The past literature survey shows that leaf springs are designed as generalized force elements where the position, velocity and orientation of the axle mounting gives the reaction forces in the chassis attachment positions. Another part has to be focused, is the automobile industry has shown increased interest in the replacement of steel spring with composite leaf spring due to high strength to weight ratio. Therefore, analysis of the composite material becomes equally important to study the behavior of Composite Leaf Spring. The objective of this report is to present modeling and analysis of composite mono leaf spring (GFRP) and compare its results. Modeling is done using Pro-E 5.0 and Analysis is carried out by using ANSYS 13.0 software.

Keywords : Composite Leaf Springs, Glass Fiber Reinforced Plastic (GFRP), Static Load Condition Etc.

I.INTRODUCTION

Leaf spring also known as flat spring is made out of flat plates. Advantage of leaf spring over helical spring is that end of the spring may be guided along the definite path as it deflect to act as a structural member in addition to the energy absorbing device. Thus the leaf spring may carry lateral load, braking torque, driving torque etc in addition to shock. In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacture in present scenario. Weight reduction can be achieved primarily by using better material, optimum design and better manufacturing process. Suspension leaf spring is one of the potential items for weight reduction in automobile. The finite element analysis (FEA) is a computing technique that is used to obtain approximate value to the boundary value problem in engineering[3]. It uses numerical technique called the finite element method (FEM). Using FEA multi leaf spring is modeled using the discrete building block called element. Each element has some equation that describes how it responds to certain load. Sum of the response of all the element of model give the total response of the design. The finite element method (FEM) was performed on the spring model to observe the distribution stress and damage.

Fig.1.1 Conventional Leaf Spring

1.1 History of Leaf Spring

There are variety of leaf spring usually, employing the word “elliptical”. “Elliptical” or “full elliptical” leaf spring referred to the two circular arc linked at their tip. This was joined to the frame at the top center to the upper arc, the bottom center was joined to the “live” suspension component such as solid front axle. Additional suspension component such as trailing arm would be needed for this design, but not for “semi-elliptical” leaf spring as used in Hotchkiss drive they employed the lower arc, hence it name “quarter-elliptic” spring often had the thickness part of the stack of leaves stuck to the rear end of the side pieces of short ladder frame, with the free end attached to the differential, as in the Austin seven of the 1920s. As an example of non-elliptical leaf spring the ford model T had multiple leaf springs over its differential that was curved in the shape of the yoke. As a substitute of damper (shock absorber), some manufacture laid the non-metallic sheet in between the metal leave such as wood. Leaf springs were common in automobile right up to the 1970s. When they Move to the front wheel drive and more sophisticated design saw the automobile manufacturers use coil spring. Instead U.S passenger car use leaf spring until 1989s.However leaf spring are still used in heavy commercial vehicle such as vans, truck and railway carriage. For heavy vehicle they had advantage of spreading the load more widely over the vehicle chassis, whereas coil spring transfer to the single point. Unlike coil spring the leaf spring also locate rear axle eliminating the need of trailing arm and pan-hard rod thereby reducing the cost and weight of simple live axle rear suspension[5]. A more modern implementation is parabolic leaf spring. This design is characterized by fewer leaves whose thickness varies from centre to the ends following parabolic curve[1]. In this design, inter-leaf friction is unwanted, and therefore there is only contact between the spring sat the ends and at the center where the axle is connected. Spacers prevent contact at other points. Aside from a weight saving, the main advantage of parabolic springs is their greater flexibility, which translates into vehicle ride quality that approaches that of coil springs.

1.2 Objective

Suspension system in automobile is very important component in deciding vehicle drive comfort, stability of vehicle. As the tyre revolves the suspension system is in dynamic state of balance, continuously compensating and adjusting for changing drive condition. Component of suspension system perform six basic functions:

I. Maintain correct vehicle ride height.
II. Reduce the effect of shock forces.
III. Maintain correct wheel alignment.
IV. Support vehicle weight.
V. Keep the tyres in contact with the road.
VI. Control the vehicles direction of travel.

Objective of project is to reduce the weight of the material used for leaf springs without any reduction on load carrying capacity and stiffness by following two methods:

I. By reducing dimensions
II. By using composite material.

II. METHODOLOGY

To achieve the required results we adopted following methodology:

I. Collection of data
II. Material Selection
III. Design of Existing Model
IV. 3D Modeling of leaf spring & calculations
V. Finite Element Analysis of leaf spring

2.1 Collection of data

In this research we selected the rear axle leaf spring of passenger car. In which we gathered the total required data which is required for our project from market survey.

Table 2.1: Specifications of Selected Application

Sr. No.	Parameters	Unit	Specifications
1	Weight of vehicle.	Kg	800
2	No of passengers.	-	8

3	Weight of each passenger.	Kg	70
4	Total weight of vehicle.	Kg	1360
5	Total weight of vehicle.	N	13350
6	Weight acting on each leaf spring.	N	3340

2.2 Material Selection

The consideration of vehicle dynamics, it is required to minimize the unsprung weight in a vehicle, the unsparing weight has to be kept as low as possible. Any amount of weight reduction achieved in unsprung weight will have a direct bearing on the fuel efficiency. It is due to this reason the weight reduction in automobiles is mainly aimed at parts such as leaf spring, drive shaft and road wheel which constitute the unsprung weight. Leaf springs constitute about 20-25% of unsprung weight several studies have received that the fuel savings in vehicles due to weight reduction is estimated to be about 0.26 gallons for every pound weight reduction could be obtained for the life period of vehicles. Further, the energy absorbed by the leaf spring is stored in the form of elastic strain energy. The elastic strain energy absorbed is equal to the work done by the external load when the leaf spring moves through a distance equal to the deflection in the spring. Therefore, the material used for the making of the leaf spring should have maximum elastic energy capacity. The energy absorbed has to be displaced faster so that the spring does not continue to oscillate after initial deflection. The energy release rate depends on the damping characteristics of the spring material. Hence, in order to arrest spring oscillation after initial deflection, the spring material should have good damping. If damping of the spring is not adequate, external damping devices such as shock absorber are used along with springs. Also, since the leaf spring is subjected to fatigue loading, the spring material should have good fatigue strength. The optimum property of truck leaf springs with respect to influence of amplitude and frequency.

2.2.1 Steel

The material used for leaf spring is usually a plain carbon steel having 0.9 to 1% carbon. According to Indian standards the recommended materials are:

1 For automobiles: 50Cr1, 50Cr1V23, and 55Si2Mn90 all used in hardened and tempered state.

2 For rail road springs: C55 (Water-hardened), C75 (oil-hardened), 40Si2Mn90 (water- hardened) and 55Si2Mn90 (oil-hardened).

3 The physical properties of some of these materials are given in the following table. All the values are for oil quenched condition and for single heat only.

Table 2.1 Physical properties of materials commonly used for leaf springs.[8]

Sr. No.	Material	Condition	Ultimate strength (N/mm^2)	Yield Strength (N/mm^2)	BHN
1	50Cr1	Hardened and tempered	1680-220	1540-1750	461-601
2	50Cr1V23		1900-2200	1900-2400	500-580
3	55Si2Mn90		1820-2200	1820-2060	440-510
4	60Si2Mn		1100-1372	1000-1225	421-563

From the table the material used for leaf spring is 55Si2Mn90[2].

Tensile yield Strength of 55Si2Mn90 material is = 1960 (N/mm^2)

2.2.2 Composite material

They are made of fiberglass, laminated bonded together by tough polyester resins. The long strand of fiberglass are saturated with resin and bundled together by wrapping or squeezed together under pressure. Fiber composite leaf spring is incredibly lightweight and processes some unique ride control characteristics. Conventional mono-leaf steel spring are real heavy weight, tipping the scale at anywhere from 25 to 45 pounds (11 to 20 kg) apiece. Some multiple-leaf springs can weight almost twice as much. A fiber composite leaf spring is featherweight by compression, weighing a mere 8 to 10 pounds (3.6 to 4.5). Reducing the weight of the suspension not only reduces overall weight of the vehicle but also reduce s the sprung mass of the suspension itself. This reduces the spring efforts and amount the shock control that is required to keep the wheel in contact with road[2]. The result is smoother riding, better handling. And faster responding suspension, which is exactly the sort of thing every performance enthusiastic wants.

2.3 Design of Existing Model

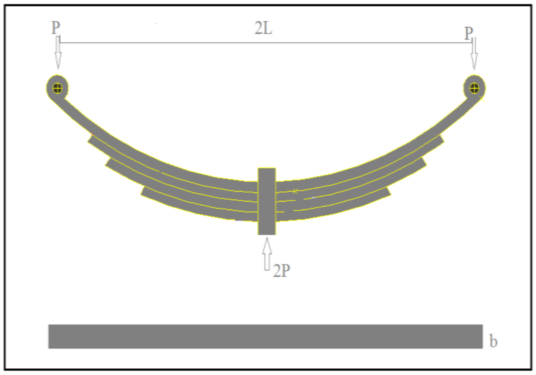

Fig 2.1 Beam Theory for Leaf Spring

Yield strength of material (S_y) =1960 N/mm^2

Factor of safety= 1.5

Permissible stresses = $\frac{Sy}{fos}$[7]

$= \frac{1960}{1.5}$

σ_t =1306.67 N/mm^2

Due to the bumping action at uneven road surface impact load is applied on the leaf spring , this force is depends on the height or depth of bump and speed of vehicle so to calculate this load at bump for static analysis we consider the 2g theory for regular road surface

According to beam theory the force applied on leaf spring (F)=2mg. Therefore the force is doubled at the time of bump , So we consider the value of Permissible stresses should be half,

$\sigma_t = \frac{1306.67}{2}$

σ_t= 653.33 N/mm^2

2.4 3D Modeling of leaf spring & calculations

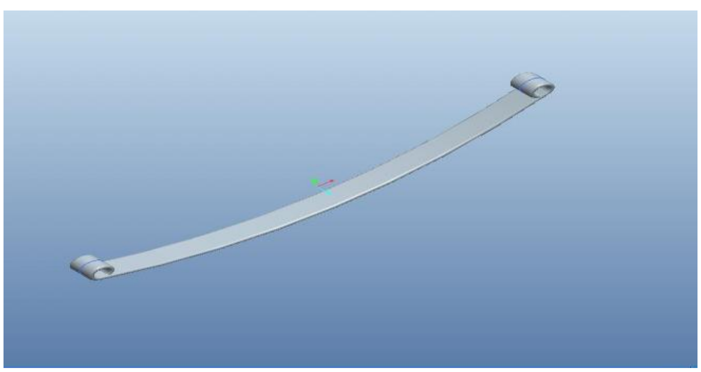

Fig.2.2 3D Model of Existing Leaf Spring

Specification of the spring are given as:

Table 2.2: Selected leaf spring specification (Existing leaf spring)

Sr. No.	Parameters	Unit	Specification
1	Load acting on the spring(2P)	N	3340
2	Young' s modulus (E)	(N/mm^2)	210000
3	Width of each leaves(b)	mm	60
4	Length of leaf spring (2L)	mm	940
5	Thickness of each leaves(t)	mm	12
6	Density of material(ρ)	kg/m^3	7850
7	Poisson's ratio(μ)	-	0.3
8	No of full length leaves (Z_F)	-	1
9	No of graduated length leaves (Z_g)	-	0

Calculations

1. Deflection of existing leaf spring[8]

$$\delta = \frac{12PL^3}{Ebt^3(2Z_g+3Z_F)}$$

$$= \frac{12\,(1670)(470)^3}{210000\,(60)(12)^3\,[2(0)+3(1)]}$$

δ=31.853mm

2. Stress on existing leaf spring.

Stress on full length leave(σ_f)

$$\sigma = \frac{18\,P\,L}{bt^2(2Z_g+3Z_F)}$$

$$= \frac{18\,(1670)(470)}{60(144)\{2(0)+3(1)\}}$$

σ = 545.69 N/mm^2

For maximum load of 3340 N the deformation and stress value calculated as **31.85 mm** and **545.069** N/mm^2 respectively.

2.5 Finite Element Analysis of leaf spring

Using Ansys, Finite element analysis is done considering material for leaf spring is 55Si2Mn90. Results are taken for 3 cases & compared with analytical results.

Table 2.3: Comparison of results by considering different cases

Sr.No.	Case I	Results	Analytical method	FEA
1.	Width of each leaf spring = 60 mm,	Deflection(mm)	55.04	64.713
2.	Thickness of each leaf spring = 10 mm, Permissible yield strength= 653.33 N/ mm^2	Stresses(N/mm^2)	784.9	859.121
	Case II			
1.	Width of each leaf spring = 60 mm,	Deflection(mm)	47.55	52.64
2.	Thickness of each leaf spring = 10.5 mm, Permissible yield strength= 653.33 N/ mm^2	Stresses(N/mm^2)	711.92	776.307
	Case III			
1.	Width of each leaf spring = 60 mm,	Deflection(mm)	41.35	46.62
2	Thickness of each leaf spring = 11 mm, Permissible yield strength= 653.33 N/ mm^2	Stresses(N/mm^2)	647.688	683.146

It is observed that by increasing thickness of leaf spring deformation & stresses are decreased. Case III gives better results.

Now, composite material is considered for leaf spring & results are seen. Following are dimensions are taken for the spring.

Width of composite leaf = 60 mm.

Thickness of composite leaf = 16 mm.

Permissible stresses of leaf = 300 N/mm^2

Properties of composite material are given in table below.

Table 2.4: Properties of E-Glass/Epoxy material[2]

Sr. No	Properties	Unit	Value
1	Tensile modulus along X-direction(Ex)	N/mm^2	34000
2	Tensile modulus along Y-direction(Ey)	N/mm^2	6530
3	Tensile modulus along Z-direction(Ez)	N/mm^2	6530
4	Tensile strength of the material	N/mm^2	900

5	Compressive strength of theMaterial	N/mm^2	450
6	Shear modulus along XY-direction(Gxy)	N/mm^2	2433
7	Shear modulus along YZ-direction(Gyz)	N/mm^2	1698
8	Shear modulus along ZX-direction(Gzx)	N/mm^2	2433
9	Poisson ratio along XY-direction(NUxy)	-	0.217
10	Poisson ratio along YZ-direction(NUyz)	-	0.366
11	Poisson ratio along ZX-direction(NUzx)	-	0.217
12	Mass density of the material (ρ),	Kg/mm^3	2.6e-6
13	Flexural modulus of the material,(N/mm^2)	N/mm^2	40000
14	Flexural strength of the material,(N/mm^2)	N/mm^2	1200

Applying boundary conditions to model, following results observed:

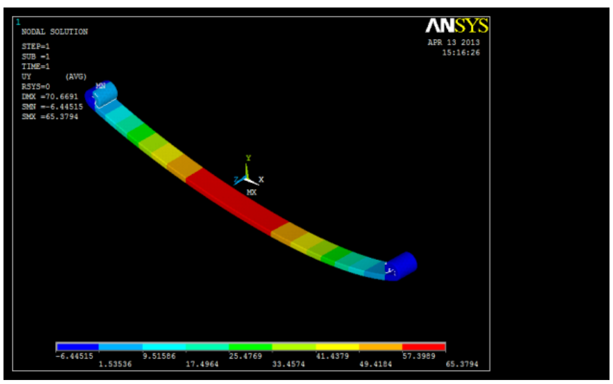

Fig 2.3: Deflection of composite leaf spring.

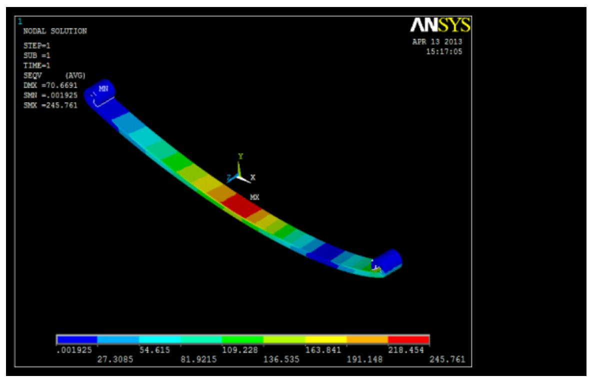

Fig 2.3: Stresses induced in composite leaf spring

Table 2.5 FEA results of composite leaf spring

Sr. No.	Composite Leaf Spring	Results	FEA
1.	Width of each leaf spring = 60 mm,	Deflection(mm)	65.00
2	Thickness of each leaf spring = 11 mm, Permissible yield strength= 653.33 N/mm^2	Stresses(N/mm^2)	245.761

III RESULT

Table 3.1 Comparison of Results

Model of leaf spring	Thickness(mm)	Max. Deflection(mm)		Max. Stress(N/mm^2)		Weight (kg)
		Analytical	FEA	Analytical	FEA	

Existing	12.0	31.85	31.94	545.07	591.71	6.21
Case-I	10.0	55.04	64.71	784.70	859.12	5.18
Case-II	10.5	47.55	52.13	711.92	733.12	5.44
Case-III	11.0	41.35	46.63	648.67	683.14	5.70
Composite	16.0	_	65.0	300.00	245.12	2.74

Composite material for leaf spring gives less stress result i.e.245.12N/mm^2 and considerable deflection comparing previous cases.

IV CONCLUSION

Modified design shows the maximum von-misses stress is below the yield stress of the material hence design is safe. As the weight of existing leaf spring is 6.22 kg and in Case 2 the weight is reduced to 5.70 kg. Hence weight reduced by 0.52 kg and which reduced the cost of material that is nothing but the cost of leaf spring. The percentage of material saved in the modified design is 8.36 %.

Under the same static load conditions deflection and stresses of steel leaf spring and composite leaf spring are found with the great difference. Deflection of Composite leaf spring is less as compared to steel leaf spring with the same loading condition. Conventional steel leaf spring was found to weigh 6.22 Kg. whereas E-Glass/Epoxy mono leaf spring weighs only 2.74 Kg. Indicating reductions in weight by 55.95% same level of performance. Conventional Leaf spring shows failure at eye end only. At maximum load condition also Composite Leaf Spring shows the minimum deflection as compared to Steel Leaf Spring. Composite leaf spring can be used on smooth roads with very high performance expectations.

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