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Design and Analysis of Leaf Spring for Heavy Weight Vehicles using Composite Materials

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Abstract**: *At present, we can find numerous leaf springs made up of steel which are utilized for the purpose of suspension of light weight to heavy weight vehicles. It is discovered that the conventional leaf springs and unsprung weight to the vehicle and diminishes its fuel efficiency. Since the composite materials are the advantage materials with higher strength to weight ration and higher corrosion resistance, they are found as the potential substitutes for these traditional metallic leaf springs. In this paper composite materials like E-Glass epoxy, S-glass epoxy, carbon fibre reinforced polymer and kelvar are used against the conventional steel for heavy weight vehicles with the objective to minimize the weight of the vehicle. Modelling of the spring is done in CATIA and analysis is carried out in ANSYS.***

Index Choice: E-Glass epoxy, S-Glass Epoxy, Carbon fiber reinforced polymer, kelvar, steel leaf spring, catia and ansys

I. INTRODUCTION

Leaf spring:

A leaf spring or laminate spring (also called as flat spring or carriage spring) is a spring which is composed of a number of plates of different lengths (also called as leaves) held together by means of clamps and bolts as shown in figure 1.

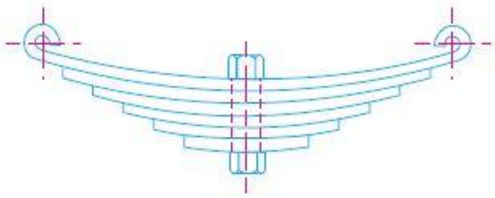

Fig 1: leaf spring

These are mostly used in automobiles. The significant stresses created in leaf springs are tensile and compressive stresses. In addition to impact loads, leaf springs can carry lateral loads, braking torque and drive torque etc.

Manufacturing Process:

The following are the steps to make a leaf spring:

1. A flat bar is cut into various lengths. After cutting these pieces are rapidly heated at the ends. Computerized machinery rolls and stretches the pieces to a tapered profile.
2. Next, its into a pressing machine which trims the stretched ends and punches holes which are used for its assembly.
3. The heated tip of the main leaf is fed into a machine that wraps it around a die form, this creates an eye mount for attaching the spring to the vehicle. Similarly, one more eye mount is created on the other side.
4. After making the eye mount all the leaves including the master leaf are heated and are individually bent to correct arc radius. While still clamped between the bending tool each leaf is quenched in oil so as to obtain high strength and correct shape.
5. Once the leaf comes out of the oil it is very much brittle i.e., it will break easily. So, it has to be tempered.
6. After tempering shot peening is done so that the surface tension of the metal is changed which further increases its strength.
7. Leaves are then assembled by a hydraulic mechanism for precise alignment. Assembling is done by means of round clips, centre bolt.

Types Of Leaf Spring:

Table 1 below shows the type of leaf springs that are generally used.

Elliptic	
Semi-elliptic	
Three quarter-elliptic	
Quarter-elliptic	
Transverse	

Table 1: Types of leaf spring

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II. LITRETURE SURVEY

[1] R.L. Daugherty published a book called "Application of composite materials to truck components" in which he examined a hybrid leaf spring and a propeller shaft which employed graphite-epoxy tubes with adhesively bonded steel end sleeves in order to develop lightweight experimental truck components. the result of his work is the hybrid design of leaf spring i.e., a spring made from the combination of steel leaves and composite leaves (fiberglass-epoxy leaves) which delivered the most cost-effective solution.

[2] Mono composite leaf spring for light weight vehicle, a paper by S Viyayrangan et al analysed a single leaf with variable thickness and width for the purpose of constant cross-section are. The outcomes demonstrated that the spring width is decreasing in hyperbolic manner and thickness is increasing linearly from the spring eyes towards the axle seat. Furthermore, the composites spring is having 85% lesser weight than that of conventional spring. The stresses and deflection obtained from the ansys were verified with analytical and experimental values.

[3] Fatigue design of leaf springs for new generation trucks by E Giannakis et al focusses on the effect of the manufacturing process of leaf spring on its performance under fatigue loading. The analysis of the micro structure and the mechanical properties of the core and the surface of the samples (prototype) reveals the deterioration of the mechanical properties of the surface due to the manufacturing process applied. The results of this investigation have been utilized as the input for analytical calculations to determine the fatigue life. The design of the mono leaf spring has been optimized and used for the stress calculations through FEA, as well as tested in constant and variable amplitude loading. The comparison between the theoretical, experimental curves and the fatigue lives seems to produce a satisfactory agreement.

[4] K. Murli, M. Gembiram et al published a paper called "Design and analysis of multi leaf spring using composite materials" which analysed a leaf spring of commercial vehicle which comprises of five graduated leaves and a full-length leaf. In this paper static structural and harmonic analysis is done for steel leaf spring and a glass fiber leaf spring. Substantial weight loss is observed which intern resulted in increased fuel efficiency. Also, there's a reduction in deformation, stress, strain which makes the spring life longer.

[5] Design and material optimization of heavy vehicle leaf spring by E VenkateshwaraRao et al examined a leaf spring consisting of 9 leaves. Static and dynamic analysis has been carried out for both steel leaf spring and composite leaf spring made from glass fiber reinforced polymer and kelvar. By observing modal analysis, it is found that the vibrations produced in the composite leaf springs are lesser than that of steel leaf spring. Suggested material for a leaf spring is the epoxt matrix composite reinforced by 50% kelvar fibers since it has less weight, frequency and stresses compared to that of steel leaf spring.

[6] TharigondaNiranjanBabu at al presented a paper on design and analysis of leaf spring with composite materials which studied a multiple leaf spring that includes seven leaves in which one is of full length. It is found that conventional leaf spring is 5.5 times heavier that the jute E-glass epoxy leaf spring.

[7] Dr. SuwarnaTorgal et al worked on multiple leaf spring having twelve leaves which comprises of five full length leaved and seven graduated leaves used in heavy commercial vehicle. Materaials which are used in this analysis are steel, Ti6Al4V alloy, S-glass fiber composite. The results obtained showed that the strength to weight ratio is more than that of steel and Ti6Al4V alloy spring is two times less in weight when compared to steel leaf spring.

[8] A Manivannam et al published a paper "Design and parametric optimization of heavy duty leaf spring" which analysed a leaf spring consisting of fourteen number of leaves comprised of 11 graduated leaves and 3 full length leaves used in medium segment heavy weight vehicles. With a vision to improve fatigue strength (which can be increased by decreasing the shear stress induced in the spring the spring is analysed with 9 different parameters. The p parameters are the orthogonal arrays. The available orthogonal arrays are L4, L8, L9, L12, L16, L18, L20, L27 and L32. Out of which L9 has given the suitable outcome.

[9] Research article named "Fatigue life assessment of 65Si7 leaf spring by Vinkel Kumar Arora provides 4 alternate methods for predicting the fatigue life of a leaf spring. The first is called the SAE spring design manual approach in which the intersection of maximum and initial stress gives the fatigue life. The second is the graphical approach which employs modified Goodman's Criteria. In the third one, codes are composed in FORTRAN to evaluate the fatigue based on analytical techniques. The fourth strategy comprises of computer aided engineering tools.

III. OBJECTIVES AND METHODOLOGY OF THE WORK

Objectives:

The main objectives of this project are:

1. Optimize the design of the leaf spring.
2. Compare the deformation, stresses, strain and strain energy stored of both the steel leaf spring and the composite leaf spring.
3. Compare the results that will be obtained from FEA with that of analytical results calculated by using the empirical formulae's.
4. Finding out the fatigue life for both the steel and composite leaf springs.

The above-mentioned objectives are done to achieve the following:

a. Substantial weight reduction which interns enhances the fuel efficiency.
b. Increase the strength which results in increment of fatigue life of the leaf spring.

Methodology Followed

The above-mentioned objectives can be accomplished by performing the following steps:

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1. Optimization can be achieved by changing the design parameters such as length, thickness or the width of the leaf spring.
2. 3D model of the leaf spring can be obtained from CATIA V6 and is analysed
3. Analysing is will be carried out in ANSYS and the results obtained for Composite Leaf Spring (CLS) and Steel Leaf Spring (SLS).
4. Fatigue life and analytical results can be calculated by using empirical formulae.

IV. MATERIALS AND THEIR PROPERTIES

The mechanical properties of the materials used is shown in the table 2 given below

Parameter	Steel	CFRP	E-Glass Epoxy	S-Glass Epoxy	Kelvar
Density (g/cm^3)	7.85	1.62	1.97	2	1.38
Youngs modulus (MPa)	$2.1X10^5$	$1.69X10^5$	41000	45000	80000
Poisons ratio	0.3	0.31	0.28	0.29	0.34
Ultimate strength(MPa)	460	2280	1140	1725	1400
Yield strength(MPa)	250	1140	570	862.5	700

Table 2: Material Properties

The composite materials used are typical unidirectional composites.

V. DESIGN PARAMETERS

Terms like datum line, effective length, span, camber, nip etc., are named as the design parameters.

Datum line: The line which passes through he focal point of the eyes is called the datum line.

Span: Distance between the centres of the eyes is referred as span or overall length.

Effective length: Length obtained by subtracting band width from span is called as effective length.

Camber: In order to obtain the strengthening effect while the spring is loaded, an initial curvature is given to the leaves. This initial curvature is called as camber.

Nip: To use the material of the spring to the maximum extent greater radius of curvature is given to the master leaf as compared to graduated leaves. This creates a gap in between the leaves this gap is called as nip which is represented as C in the figure 2 shown below.

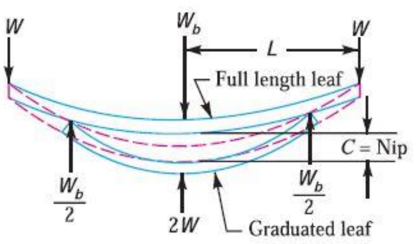

Fig 2: Representation of nip in a leaf spring.

VI. THEORITICAL APPROACH

For a multiple leaf spring maximum bending stress is given as

$$\sigma = \frac{6WL}{n.bt^2}$$

Deflection can be written as

$$\delta = \frac{6WL^3}{n.E.bt^3} = \frac{\sigma L^2}{Et}$$

Stiffness of the spring is given by

$$k = \frac{8nEbt^3}{3L^3}$$

Where, W is the Load (N).
L is the effective length (mm).
N is the number of leaves.
b is the width of the leaves (mm).
t is the thickness of the leaves (mm).
E is young's modulus (MPa).

Also, the load carried out in full length leaves is written as

$W_F = \left(\frac{3n_F}{3n_F+2n_G}\right) W$ and

Load carried by graduated leaves is

$$W_G = \left(\frac{2n_G}{3n_F + 2n_G}\right) W$$

Where, n_F is the number of full length leaves.
n_G is the number of graduated leaves.

Fatigue life can be predicted analytically by using the relations given by Hwang and Han (1986) which is written as

$$N=\{B(1-r)\}^{1/C}$$

Where,
N is the number of cycles a leaf spring can withstand without failure.
B is the constant=10.33
C is also a constant=0.14012
r is the applied stress level

$$r = \frac{maximum\ \ stress}{ultimate\ \ strength}$$

VII. SPECIFICATION OF LEAF SPRING

The specification of the modelled leaf spring is
Number of leaves, n = 14
Number of full length leaves, n_F = 3
Number of graduated leaves, n_G = 11
Camber, y= 210 mm
Width of the leaves, b= 80 mm
Thickness of the leaves, t= 12mm

S.No	Length of the leaves (mm)
1	362
2	439
3	516
4	593
5	670
6	748
7	825
8	902
9	979
10	1056

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11	1133
12	1537
13	1537
14	1537

Table 3: length of the leaves.

Table 3 shows the length of the leaves which are used in modelling

VIII. MODELLING

The leaf spring has been modelled in CATIA V6 R20, it has lots of features available that enable the users to model any part without any difficulties. Some features of Catia which are used in this work are pad – this extrudes the sketch drawn, shaft – this will add material with refence to axis rotation, groove – this is similar to shaft but it removes the material, axis constraint – as the name itself says that it adds a constraint to axis for restricting the rotation while assembling, face to face constraint.

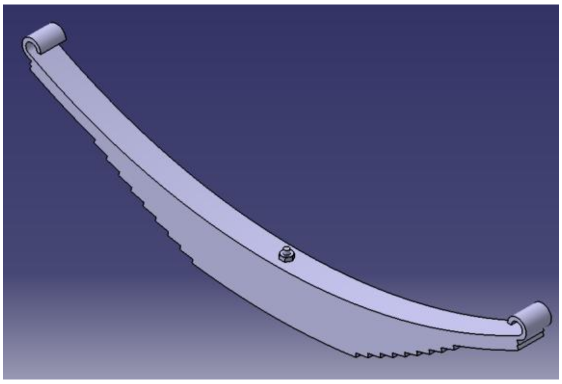

Fig 3: model of the leaf spring

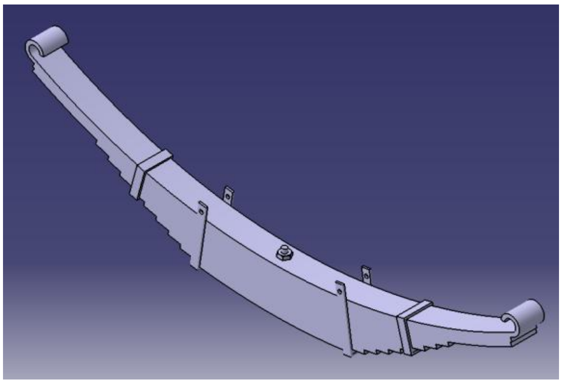

Fig 4: assembled leaf spring

Figure 3 depicts the model of leaf spring that will be imported into the ANSYS and analysed.

While figure 4 shows the leaf spring which is assembled by means of centre bolt and two types of rebound clips (rectangular rebound clip and square end rebound clip).

IX. ANALYSIS OF LEAF SPRING

The leaf spring has been analysed using ANSYS 14.5. Firstly, the model shown in figure 3 is converted to IGES format and then imported in Ansys for static structural analysis. The steps involved in it are as follows:

1. Open ANSYS workbench, in the analysis systems toolbar double click on static structural.
2. In engineering data give the properties of material. Import the desired model.
3. After importing, mesh the model and apply the boundary conditions and the load.
4. In the solution tool bar insert total deformation, equivalent von-mises stress, equivalent von-mises strain, shear stress and strain energy.
5. Click on solve button to get solution for the above-mentioned parameters.

Boundary Conditions:

1. One of the eye end of the leaf spring is fixed. That means this end is rigidly connected to the axle of the vehicle.
2. The other eye end is set to free in horizontal direction. This justifies that the spring will be straighten when load is applied.
3. The load is applied at the master leaf of the spring.

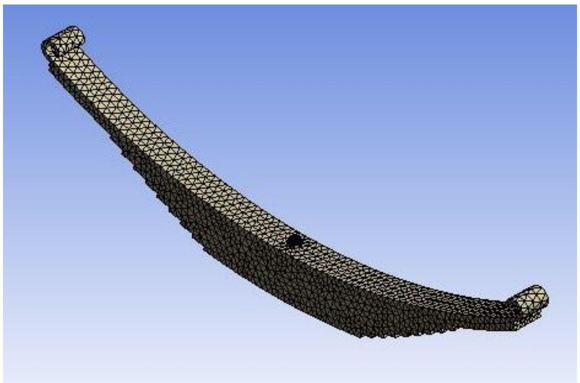

Fig 5: Meshed leaf spring model

The above figure 5 shows the leaf spring on to which triangular meshed has been done with an element size of 5.

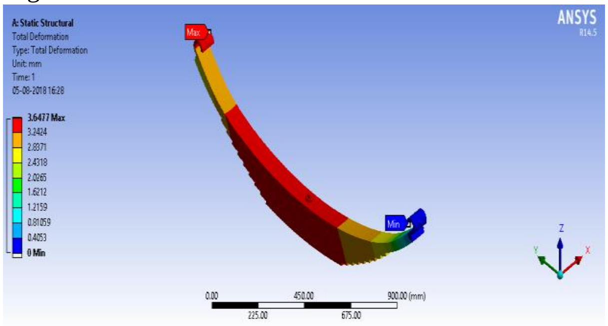

Fig 6: Deformation

Figure 6 shows the total deformation induced in the leaf spring. Maximum shear stress is occurred at one of eye ends which is represented by red label in figure 6.

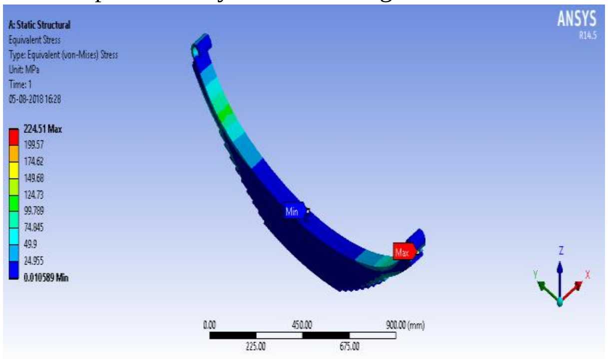

Fig 7: Stress

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The above figure 7 shows the equivalent stress induced in the spring. Maximum shear stress occurs at one of the eye ends.

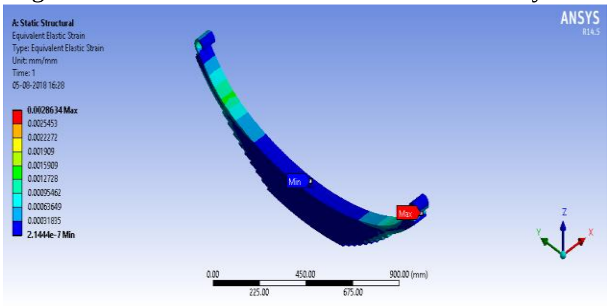

Fig 8: Strain

Figure 8 shows the strain which is also maximum at one of the eye ends.

X. RESULT AND DISCUSSION

Material	Deformation (mm)	Stress (MPa)	
		Min	Max
STEEL	1.4625	0.0089	221.35
CFRP	1.7298	0.0092	222.05
E-GLASS EPOXY	7.1409	0.0083	220.12
S- GLASS EPOXY	6.5062	0.0083	220.12
KELVAR	3.6477	0.0105	224.51

Table 4: Equivalent stress and deformation

The above table 4 shows the stress and deformation for both the steel leaf spring and composite leaf spring. The theoretical stress which is obtained from empirical formula is 400MPa. Hence the Ansys results can be justified since it has the stress value less than that of theoretical values.

Materials	Strain		Strain energy (MJ)
	Minimum	Maximum	
STEEL	$0.77236X10^{-7}$	0.00112	44.54
CFRP	$0.93986X10^{-7}$	0.00134	72.33
E-GLASS EPOXY	$3.5699X10^{-7}$	0.00547	220.02
S-GLASS EPOXY	$3.2507X10^{-7}$	0.00499	200.47
KELVAR	$2.1444X10^{-7}$	0.00286	107.81

Table 5: strain and strain energy for both steel and composite leaf spring.

Table 5 shows the equivalent von-mises strain and strain energy stored in the leaf spring.

Material	Deformation (mm)	
	Before Optimization	After Optimization
STEEL	1.4625	---
CFRP	1.7298	1.6291
E-GLASS EPOXY	7.1409	6.7248
S-GLASS EPOXY	6.5062	6.127
KELVAR	3.6477	3.4354

Table 6: Comparison of deformation before optimization and after optimization.

By undergoing trial and error process it is found that the design is best optimized by increasing the width of the leaf spring by 5 mm. Table 6 shows the comparison of deformation before and after optimization.

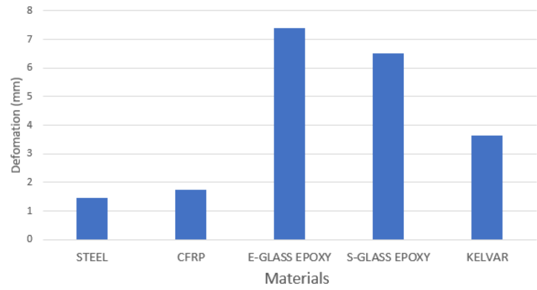

Fig 9: comparison of materials based on deformation

Figure 9 demonstrates the variation of deformation for composite leaf spring and steel leaf spring. From the graph it is clear that the maximum deformation occurs in E-Glass epoxy because it has lesser young's modulus as compared to other materials.

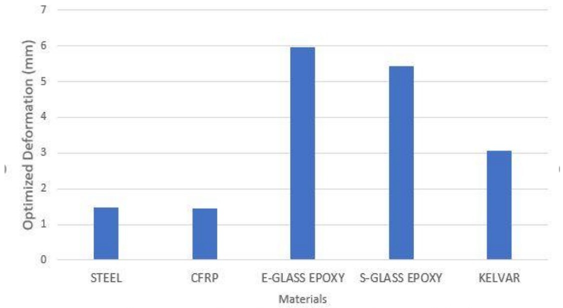

Fig 10: comparison of materials based on optimized deformation.

Figure 10 shows the variation of optimized deformation for both the steel leaf spring and composite leaf spring. From figure 10 it is obvious that the maximum deformation occurs in E-Glass epoxy because it has lesser young's modulus compared to other materials.

Material	Number of cycles to failure
STEEL	603419
CFRP	8143497
E-GLASS EPOXY	3513571
S-GLASS EPOXY	6393445
KELVAR	4977041

Table 7: Fatigue life of the steel and composite leaf spring.

From table 7 it is observed that the fatigue life of the steel leaf spring is very much less than that of composite leaf spring.

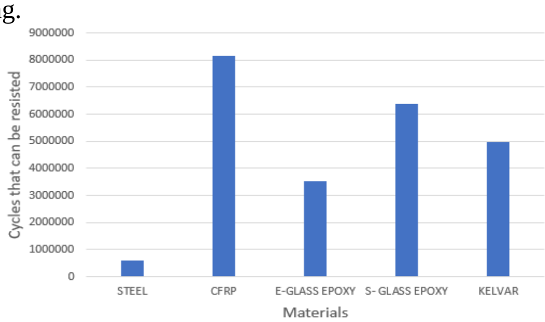

Fig 11: Graphical representation of fatigue life.

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Figure 11 shows the variation of fatigue life for both steel leaf spring and composite leaf spring. It can be observed that CFRP is having more fatigue life than all materials because it has the highest ultimate strength compared to other materials.

XI. CONCLUSIONS

A leaf spring is designed to resist a load of 23KN. By observing the results, it can be concluded that

1. Kelvar is preferred because it is having 82.42% lesser weight than the steel leaf spring. And also, the deformation is in the range of safe value.
2. By trial and error process, the best possible optimization is achieved by increasing the width of the spring by 5mm.
3. The fatigue life of leaf spring made up of kelvar has 8 times more fatigue life than the steel leaf spring. Hence it cost-effective.

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