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Modelling and Analysis of Suspension System of TATA SUMO by using Composite Material under the Static Load Condition by using FEA

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Abstract- In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturer 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 automobile as it accounts for ten to twenty percent of the unsprung weight. This helps in achieving the vehicle with improved riding qualities. It is well known that springs, are designed to absorb and store energy and then release it. Hence, the strain energy of the material becomes a major factor in designing the springs. It can be easily observed that material having lower modulus and density will have a greater specific strain energy capacity. The introduction of composite materials was made it possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness. Since; the composite materials have more elastic strain energy storage capacity (1) and high strength-to-weight ratio as compared to those of steel.

It is seen that from the graph that when load increases the bending stress increases linearly. So load-stress graph gives the straight line relationship. At lower loads both theoretical and ANSYS results are very close, but when load increases the ANSYS results are uniformly reduced compared to theoretical results.The deflection in steel leaf spring is less as compared to the composite leaf spring as shown in the above graphs.

Springs are placed between the road wheels and the body. When the wheel comes across a bump on the road, it rises and deflects the spring, there by storing energy there in. On releasing, due to the elasticity of the spring material, it rebounds there by expending the stored energy. In this way the spring starts vibrating, of course, with amplitude decreasing gradually on account of internal friction of the spring material and friction of the suspension joints, till vibrations die down.

Keywords- leaf spring, FEM, strain energy, strength to weight ratio, etc.

I. INTRODUCTION

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 project is to present modeling and analysis of composite mono leaf spring and compare its results. Modelling is done using Pro-E (Wild Fire) 5.0 and Analysis is carried out by using ANSYS 10.0 software for better understanding. It is seen that the Composite leaf spring (CARBON FIBRE/E-POXY) weight is 2.7 times less as compared to steel leaf spring for same stiffness (same load carrying capacity).Composite leaf spring's (CARBON FIBRE/E-POXY) natural frequency is 1.93 times more as compared to steel leaf spring for same stiffness.

All the analysis for the composite leaf spring is done by using ANSYS 13.0. For composite leaf spring ,the same parameters are used that of conventional leaf spring.So, a virtual model of leaf spring was created in Pro-E. Model is imported in ANSYS and then material is assigned to the model. These results can be used for comparison with the conventional steel leaf spring.

II. LITERATURE REVIEW

Many industrial visits, past recorded data shows that steel leaf springs are manufactured by EN45, EN45A, 60Si7, EN47, 50Cr4V2, 55SiCr7 and 50CrMoCV4 etc.These materials are widely used for production of the parabolic leaf springs and conventional multi leaf springs.Leaf springs absorb the vehicle vibrations, shocks and bump loads (Induced due to road irregularities) by means of spring deflections, so that the potential energy is stored in the leaf spring and then relieved slowly [1]. Ability to store and absorb more amount of strain energy ensures the comfortable suspension system. Many suspension systems work on the same principle including conventional leaf springs. However, for the same load and shock absorbing performance, conventional (steel) leaf springs use excess of material making them considerably heavy. This can be improved by introducing composite materials in place of steel in the conventional spring. Studies and researches were carried out on the applications of the composite materials in leaf spring [1], [2]. A composite mono leaf spring with an integral eye was manufactured and tested for the static load conditions [2]. Fatigue life prediction was also done by authors so as to ensure a reliable number of life cycles of a leaf spring. Further, a leaf spring had been modeled in conventional way and simulated for the kinematic and dynamic comparatives [3]. Cyclic creep and cyclic deformation was also studied [4]. Efforts were taken for Finite Element Analysis of multi leaf springs. These springs were simulated and analyzed by using ANSYS 7.1[5]. Premature failure in leaf springs was also studied so as to suggest remedies on application of composite leaf springs. [6], [7], [8].

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III. DESIGN OF CARBON FIBRE/E-POXY MONO-LEAF SPRING

Considering several types of vehicles that have leaf springs and different loading on them, various kinds of composite leaf spring have been developed. In multi-leaf composite leaf spring, the interleaf spring friction plays a spoil spot in damage tolerance. It has to be studied carefully.

The following cross-sections of mono-leaf composite leaf spring for manufacturing easiness are considered.

1. Constant thickness, constant width design.
2. Constant thickness, varying width design.
3. Varying width, varying thickness design.

In this, only a mono-leaf composite leaf spring with Constant thickness, constant width is designed and manufactured.

A. Material properties of Carbon fiber/E-poxy

Table no. 1 Material properties of Carbon fiber/E-poxy

S.N	**Properties**	**Value**
1	Tensile modulus along X-direction (Ex), MPa	62000
2	Tensile modulus along Y-direction (Ey), MPa	48000
3	Tensile modulus along Z-direction (Ez), MPa	48000
4	Tensile strength of the material, MPa 900	1830
5	Shear modulus along XY-direction (Gxy), MPa	3270
6	Shear modulus along YZ-direction (Gyz), MPa	3270
7	Shear modulus along ZX-direction (Gzx), MPa	1860
8	Poisson ratio along XY-direction (NUxy)	0.22
9	Poisson ratio along YZ-direction (NUyz)	0.22
10	Poisson ratio along ZX-direction (NUzx)	0.30
11	Mass density of the material (ρ), Kg/mm	1580

B. Dimensions of Composite Leaf Spring

Table no. 2 Design Parameter for composite leaf spring

Sr. No.	Parameters	Dimensions in (mm)
1	Total Length of the spring (Eye to Eye)	1540 mm
2	Free Camber (At no load condition)	136 mm
3	No. of full length leave (Master Leaf)	01
4	Thickness of leaf	13 mm
5	Width of leaf spring	70 mm
6	Maxm Load given on spring	25 Kg
7	Weight of the leaf spring	23 Kg

IV. DESIGN OF STEEL MONO-LEAF SPRING

A. Materials of leaf springs

The material used for leaf spring is usually a plain carbon steel having 0.90 to 1.0% carbon. The leaves are heat treated after the forming process. The heat treatment of spring steel produces greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties.

According to Indian standards, the recommended materials are:

1. For automobiles : 50 Cr 1, 50 Cr 1 V 23, and 55 Si 2 Mn 90 all used in hardened and tempered state.
2. For rail road springs: C 55 (water-hardened), C 75 (oil-hardened), 40 Si 2 Mn 90 (water-hardened) and 55 Si 2 Mn 90 (oil-hardened).
3. The physical properties of some of these materials are given in the following table. All values are for oil quenched condition and for single heat only.

The test steel leaf spring used for experiment is made up of 60Si7. The composition of material is 0.56 C%, 1.80 SI%, 0.70 Mn%, 0.045 P%, 0.045 S%. Following are the parameters for the 60Si7

Table no. 3 Physical properties of materials commonly used for leaf springs.

Material	Condition	Ultimate tensile strength (MPa)	Tensile yield strength (MPa)	Brinell hardness number
50 Cr 1	Hardened and Tempered	1680-2200	1540-1750	461-601
50 Cr 1 V 23		1900-2200	1680-1890	534-601
55 Si 2 Mn 90		1820-2060	1680-1920	534-601

V. THREE-DIMENSIONAL FINITE ELEMENT ANALYSIS

CAD Modeling of any project is one of the most time consuming process. One cannot shoot directly from the form sketches to Finite Element Model. CAD Modeling is the base of any project. Finite Element software will consider shapes, whatever is made in CAD model. Although most of the CAD Modeling software have capabilities of analysis to some extent and most of Finite Element software have capabilities of generating a CAD model directly for the purpose of analysis, but their off domain capabilities are not sufficient for large and complicated models which include many typical shapes of the product. The model of the multi leaf spring structures also includes many complicated parts, which are difficult to make by any of other CAD modeling as well as Finite Element software.

Modeling is done using Pro-E (Wild Fire) 4.0 and Analysis is carried out by using ANSYS 13.0 software for better understanding. SOLID187 element is a higher order 3-D, 10-node element. SOLID187 has a quadratic displacement behavior and is well suited to modeling irregular meshes (such as those produced from various CAD/CAM systems). The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials. The MPC184 rigid link/beam element can be used to model a rigid constraint between two deformable bodies or as a rigid component used to transmit forces and moments in engineering applications. This element is well suited for linear, large rotation, and/or large strain nonlinear applications.

Also, analysis carried out for composite leaf spring with eyes and the results were compared with steel leaf spring with eye end. Figs. 5 to 14 represent FEA results for steel and mono composite leaf spring (Carbon Fiber/Epoxy). The load, deflection for Carbon Fiber/Epoxy and for steel were measured and plotted as shown in Figs. 5.1 and 5.

A. Von Mises Stress for Composite Material at load of 5 Kg, 10 Kg, 15Kg, 20 Kg & 25 Kg

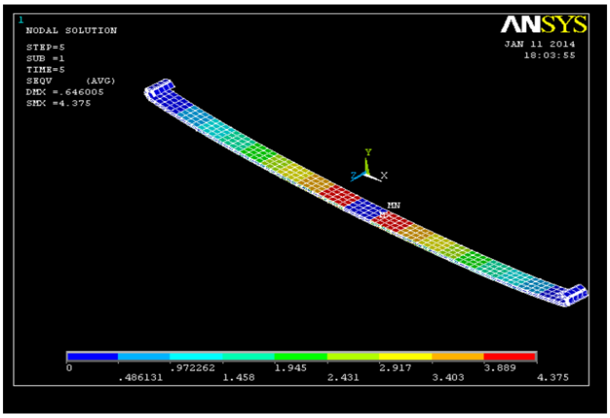

Fig. no.1 Von Mises Stress at load of 5 Kg.

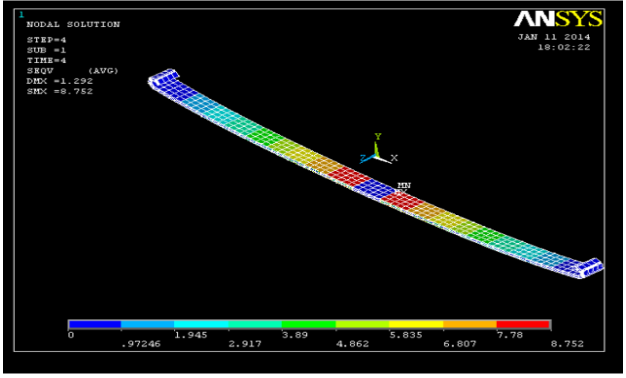

Fig. no.2 Von Mises Stress at load of 10 Kg.

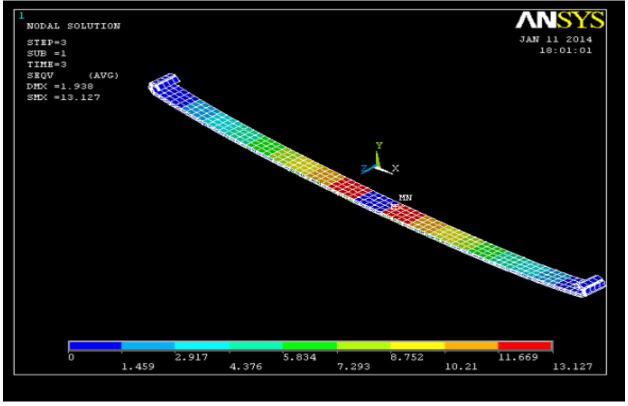

Fig. no.3 Von Mises Stress at load of 15 Kg.

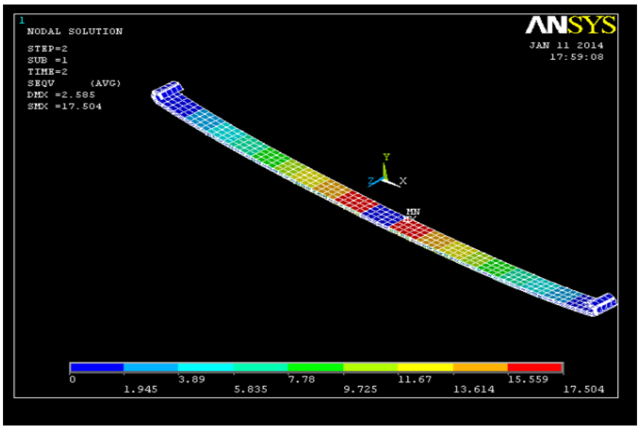

Fig. no.4 Von Mises Stress at load of 20 Kg.

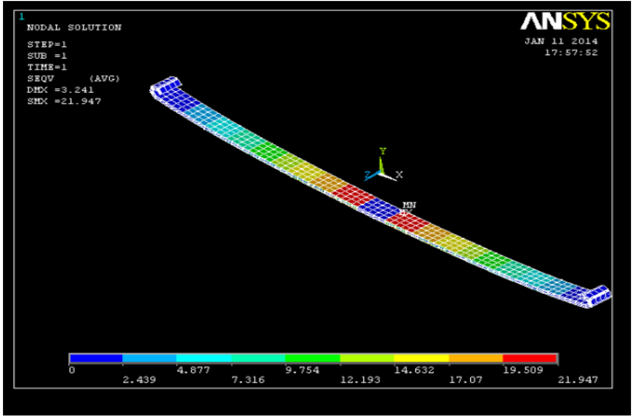

Fig. no.5 Von Mises Stress at load of 25 Kg.

B. Von Mises Stress for Steel Material at load of 5 Kg, 10 Kg, 15Kg, 20 Kg & 25 Kg

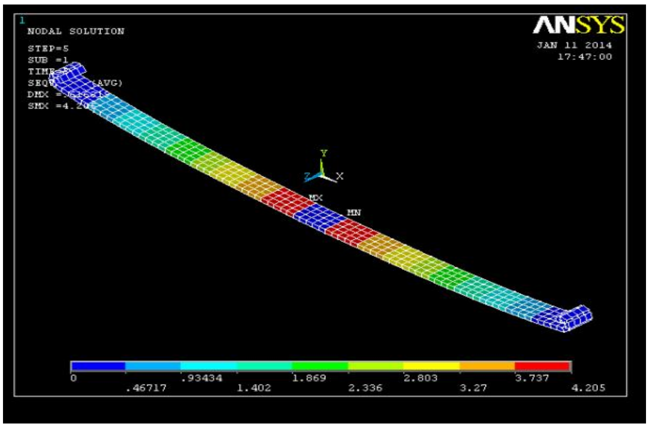

Fig. 6 Von Mises Stress at load of 5 Kg.

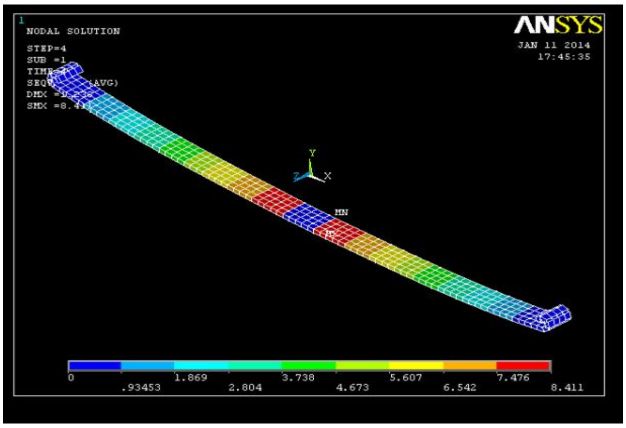

Fig. 7 Von Mises Stress at load of 10 Kg.

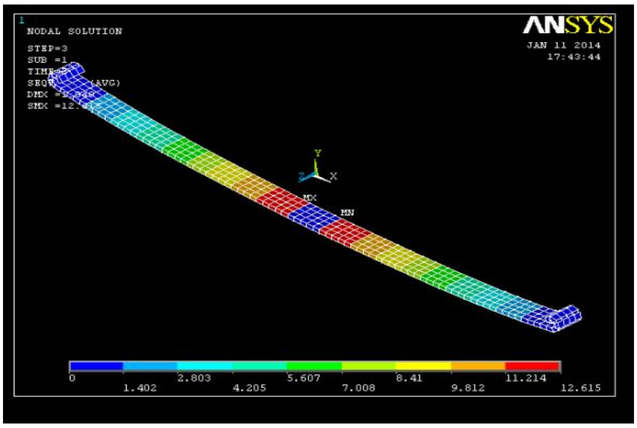

Fig. 8 Von Mises Stress at load of 15 Kg.

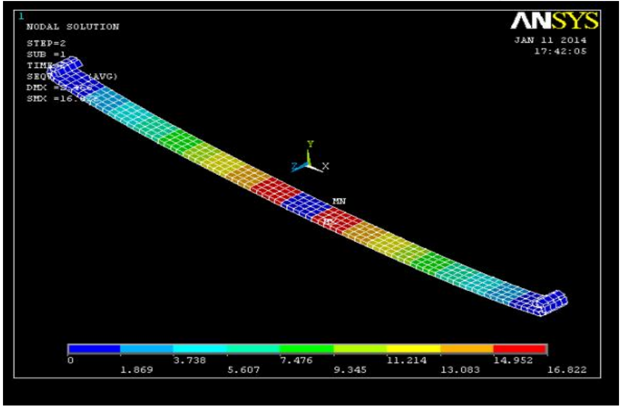

Fig. no.9 Von Mises Stress at load of 20 Kg.

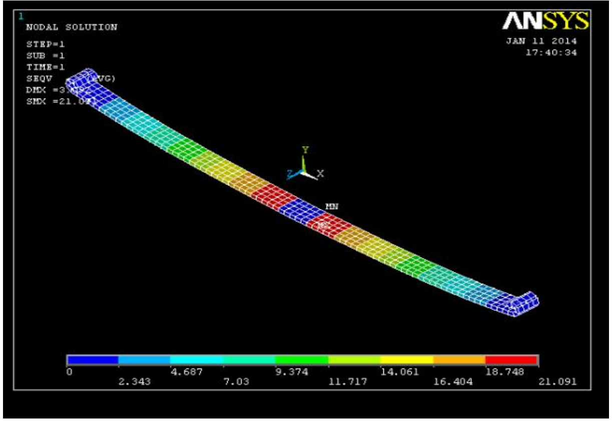

Fig. no.10 Von Mises Stress at load of 25 Kg.

C. Load vs Deflection for Composite & Steel Mono Leaf Spring-

The load, deflection for steel as shown in Fig.

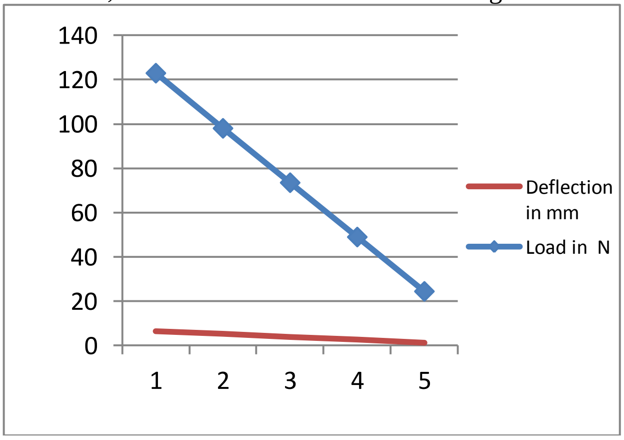

Fig. no.11 The load, deflection curve for steeL

The load, deflection for Carbon Fiber/Epoxy as shown in Fig.

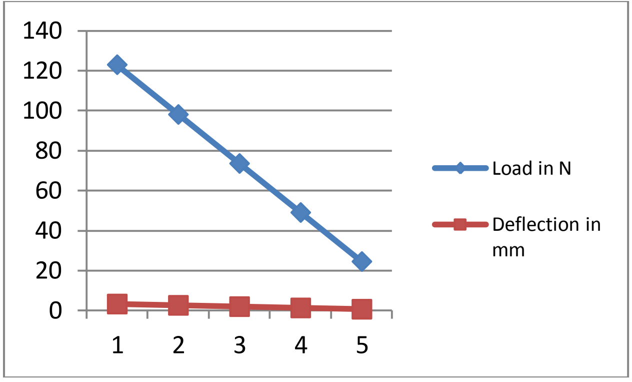

Fig. no. 12 The load, deflection curve for composite.

D. Load vs Deflection for Composite Mono Leaf Spring at load of 5 Kg, 10 Kg, 15Kg, 20 Kg & 25 Kg

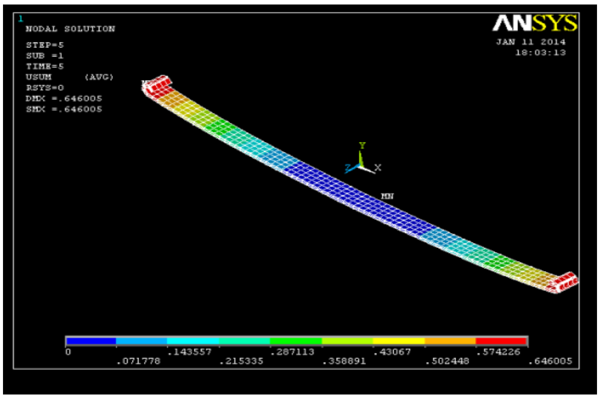

Fig. no.13 Load vs Deflection at load of 5 Kg.

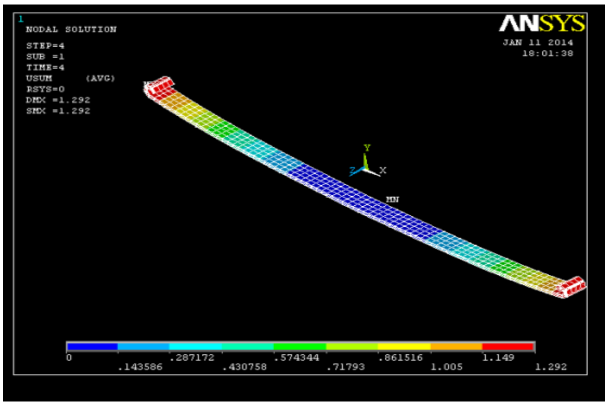

Fig. no. 14 Load vs Deflection at load of 10 Kg.

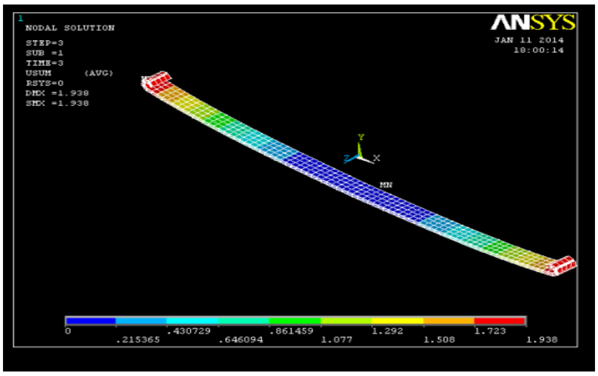

Fig. no. 15 Load vs Deflection at load of 15 Kg.

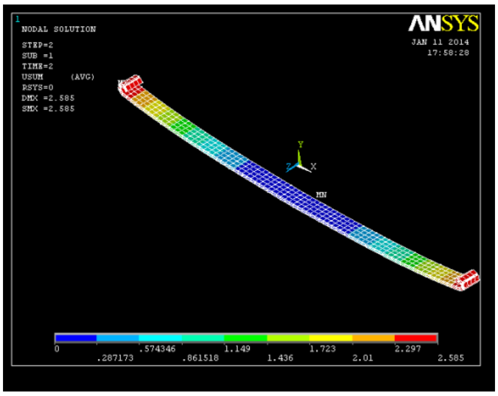

Fig. no. 16 Load vs Deflection at load of 20 Kg.

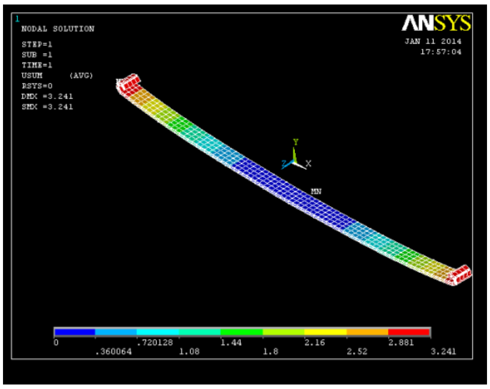

Fig. no. 17 Load vs Deflection at load of 25 Kg.

E. Load vs Deflection for steel Mono Leaf Spring at load of 5 Kg, 10 Kg, 15Kg, 20 Kg & 25 Kg

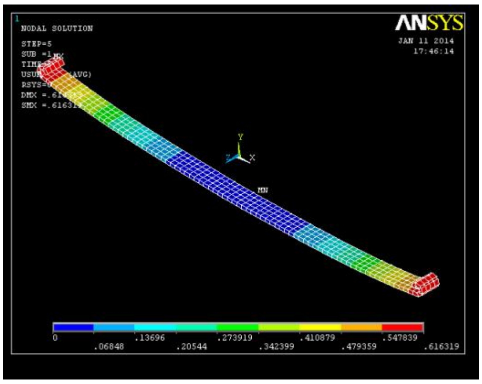

Fig.no. 18 Load vs Deflection at load of 5 Kg.

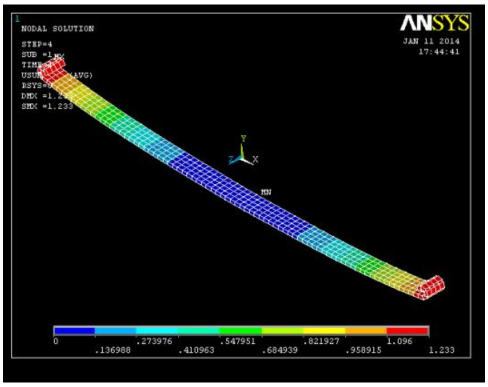

Fig.no. 19 Load vs Deflection at load of 10 Kg.

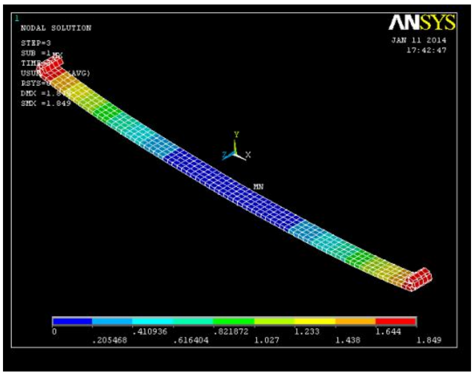

Fig. no.20 Load vs Deflection at load of 15 Kg.

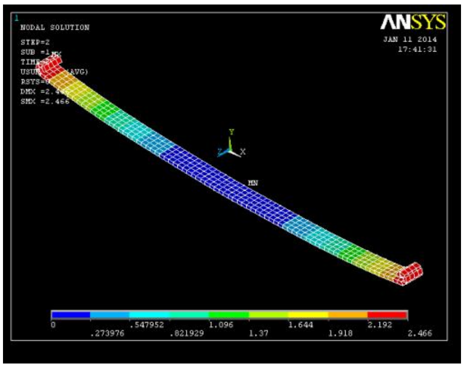

Fig. no.21 Load vs Deflection at load of 20 Kg.

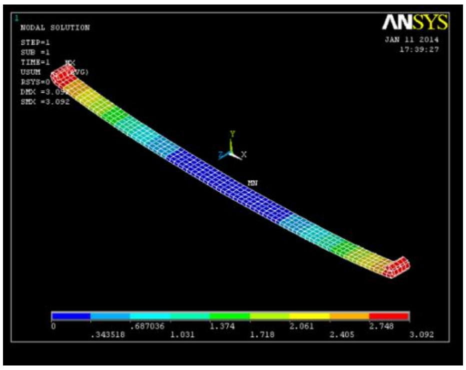

Fig.no.22 Load vs Deflection at load of 25 Kg.

VI. ANALYTICAL ANALYSIS OF LEAF SPRING

Leaf springs (also known as flat springs) are made out of flat plates. The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. Thus the leaf springs may carry lateral loads, brake torque, driving torque etc., in addition to shocks. Consider a single plate fixed at one end and loaded at the other end.

This plate may be used as a flat spring.

Let

t = thickness of plate

b = width of plate, and

L = length of plate or distance of the load W from the cantilever end, as shown in the Figure 1.

We know that the maximum bending moment at the cantilever end

$M = W.L$

And section modulus,

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$Z = I/y$
where $I = (b.t3 / 12)$ and $Y = t/2$
So $Z = b.t2 / 6$
The bending stress in such a spring,
$\sigma b = M / Z = (6W.L) / b.t2$ …………………………………… .. (i)

We know that the maximum deflection for a cantilever with concentrated load at free end is given by
$\delta = W.L3 / 3.E.I = 2f.L2 / 3.E.t$ …………………….. (ii)

It may be noted that due to bending moment, top fibers will be in tension and bottom fibers are in compression, but the shear stress is zero at the extreme fibers and the maximum at centre, hence for analysis, both stresses need not to be taken into account simultaneously. We shall consider bending stress only.If the spring is not of cantilever type but it is like a simply supported beam, with length 2L and load2W in the centre.

Maximum bending moment in the centre,
$M = W.L$
Section modulus
$Z = b.t2 / 6$
Bending stress
$\sigma b = 6W.L / b.t2$

We know that maximum deflection of a simply supported beam loaded in the centre is given by
$\delta = W.L3 / 3.E.I$

From above we see that a spring such as automobile spring (semi-elliptical spring) with length 2L and load in the centre by a load 2W may be treated as double cantilever. If the plate of cantilever is cut into a series of n strips of width b and these are placed as shown in Figure 1, then equations (i) and (ii) may be written as
$\sigma b = 6W.L / n.b.t2$ ………………………….. (iii)
$\delta = 4.W.L3 / n.E.b.t3 = 2. \sigma b.L2 /3.E.t$ …………… (iv)

The above relation gives the bending stress of a leaf spring of uniform cross- section and is given in Table 1 at various loads. The stress at such a spring is maximum at support.

Analytical stresses and deflections of leaf spring can be calculated as

Analytical stress is calculated by

$$\sigma b = 6\ WL / n\ bt^2$$

Analytical deflection is given by

$$\delta = (4 \times W \times L^3) / (n \times E \times b \times t^3)$$

A. Calculation of Analytical Stresses for Steel

Analytical stress is calculated by

$$\sigma b = 6\ WL / n\ bt^2$$

1. For 2W= 25 Kg, W=12.5 Kg=12.5x 9.81= 122.62 N, 2L=1540 mm, L= 770 mm, t= 13 mm & b=70 mm, n=1
   σb=6x122.62x770/(1x70x13^2)
   =47.88 N/mm2

Similarly,
2. for 2W=20 Kg, σb = 38.31 N/mm2
3. for 2W=15 Kg, σb = 28.73 N/mm2
4. for 2W=10 Kg, σb = 19.15 N/mm2
5. for 2W=5 Kg, σb = 9.57 N/mm2

B. Calculation of Analytical Deflection for Steel

Analytical deflection is given by

$$\delta = (4 \times W \times L^3) / (n \times E \times b \times t^3)$$

1. For 2W= 25 Kg, W=12.5 Kg=12.5x 9.81= 122.62 N, E=22426.09x 9.81 N/mm2
   δ = (4 x 122.62x770^3) / (1x 22426.09x9.81 x 70 x 13^2)
   = 6.618 mm

Similarly
2. for 2W=20 Kg, δ = 5.294 mm
3. for 2W=15 Kg, δ = 3.970 mm
4. for 2W=10 Kg, δ = 2.647 mm
5. for 2W=5 Kg, δ = 1.323 mm

VII. RESULT AND DISCUSSION

The objective of this study is to evaluate the applicability of a composite leaf spring in automobiles by considering cost-effectiveness, riding comfort and strength. The comparison between multi-leaf spring and mono-leaf composite spring is made for the same requirements and loading conditions. The comparison is based on four major aspects such as stresses,deflection, weight, riding comfort, cost and strength.

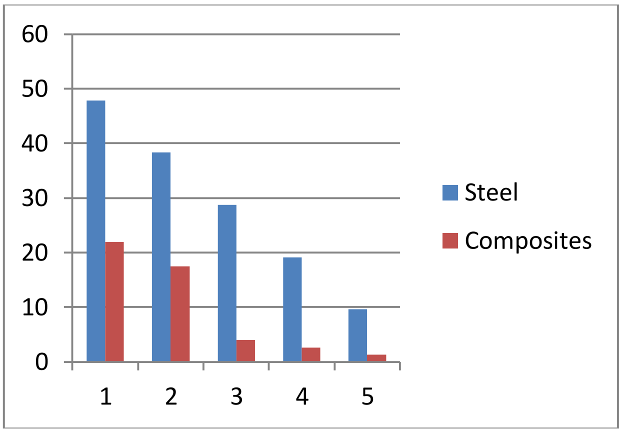

Fig. no.22 Stresses for Steel vs. Composites

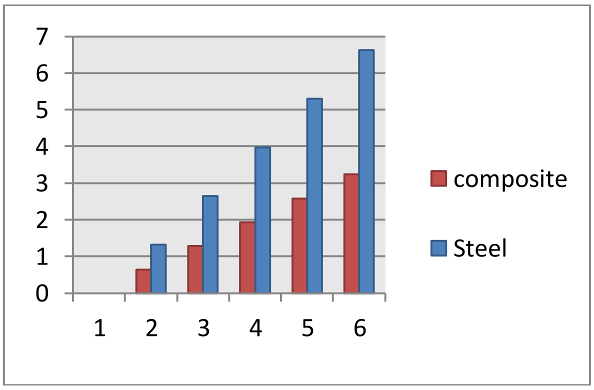

Fig. no. 23 Deflection for Steel vs. Composites

A. Stresses & Delection in Leaf Spring-

It is seen that from the graph that when load increases the bending stress increases linearly. So load-stress graph gives the straight line relationship. At lower loads both theoretical and **ANSYS** results are very close, but when load increases the ANSYS results are uniformly reduced compared to theoretical results.The deflection in steel leaf spring is less as compared to the composite leaf spring as shown in the above graphs & it will also from the above table.

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B Comparison of Rigidity Qualities

The weight reduction of unsprung mass of an automobile will improve the riding quality. The suspension leaf contributes 10% - 20% of the unsprung mass. The weight of the composite leaf spring is 3.75 times less than steel leaf spring. Hence the riding comfort of an automobile is increased due to the replacement of the steel leaf spring by composite leaf spring. No one to the best of knowledge has worked but qualitatively on how much improvement in mileage/lit of passenger vehicle occurs and how much riding comfort improves. Only qualitative information is available on riding comfort of vehicle with respect to its unsprung mass. Steel spring is a multi-leaf spring and its inter-leaf fabrication reduces its riding quality. But composite leaf spring is a mono-leaf spring and more conductive to riding qualities.

C. Cost Comparison

The cost estimation of composite leaf spring provides a clear economic viability of the product in comparison to that of a convectional leaf spring.

Table No. 4 Comparision in Stresses & Deflection for Composite & Steel Leaf Spring

Sr. No.	Wt.	Conventional Steel leaf spring		Virtual model of Composite Leaf Spring (FEA)	
		Sress, N/mm 2	Deflection, mm	Sress, N/mm2	Deflection, mm
1.	25Kg	47.88	6.618	21.94	3.241
2.	20Kg	38.31	5.294	17.50	2.585
3.	15Kg	28.73	3.970	13.27	1.938
4.	10Kg	19.15	2.647	8.75	1.292
5.	5 Kg	9.57	1.323	4.37	0.646

VII. CONCLUSION

The automobile chassis is mounted on the axles, not direct but with some form of springs. This is done to isolate the vehicle body from the road shocks which may be in the form of bounce, pitch, roll or sway. These tendencies give rise to an uncomfortable ride and also cause additional stress in the automobile frame and body.

All the part which performs the function of isolating the automobile from the road shocks are collectively called a suspension system. Leaf spring is a device which is used in suspension system to safeguard the vehicle and the occupants. For safe and comfortable riding i.e, to prevent the road shocks from being transmitted to the vehicle components and to safeguard the occupants from road shocks it is necessary to determine the maximum safe load of a leaf spring. Therefore in the present work, leaf spring is modeled and static analysis is carried out by using ANSYS software.

It is seen that from the graph that when load increases the bending stress increases linearly. So load-stress graph gives the straight line relationship. At lower loads both theoretical and **ANSYS** results are very close, but when load increases the ANSYS results are uniformly reduced compared to theoretical results. It is obvious that maximum stress developed is at inner side of the eye sections i.e. the red color indicates maximum stress, because the constraints applied at the interior of the eyes. Since eyes are subjected to maximum stress, care must be taken in eye design and fabrication and material selection. The material must have good ductility, resilience and toughness to avoid sudden fracture

Since, the composite leaf spring is able to with stand the static load as well as the fatigue load, it is concluded that there is no objection from strength point of view also, in the process of replacing convectional leaf spring by composite leaf spring. To establish the consistency of test results, extensive trail on a large scale has to carry out. This requires large time and infrastructure, which are beyond the scope of the present study. The major disadvantage of composite leaf springs is cost and resistance. In this study, the cost factor has been proved to be ineffective. However the matrix material is likely to chip off when it is subjected to poor road environment (i.e. if some stone hit the composite leaf spring then it may produce chipping), which may sometimes break the fibers in the lower portion of the spring. This may result in a loss of capability to share flexural stiffness. But this depends on the condition of the road. In normal road condition, this type of problems will not occur.

VIII. FUTURE SCOPE

After carrying out the present work, it is found that the following things can be added as an extension to this work-

As analysis of composite leaf spring & steel leaf spring is validated by the analytical results, so one can validate with manufacturing of actual prototype of composite & steel leaf spring by testing on universal testing machine(UTM).

As this analysis is under static load condition, so one can go for the analysis of composite & steel leaf spring under dynamic loading condition.

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