Design and Analysis of Jute/E-Glass/Epoxy Composite Mono Leaf Spring of Varying Cross-Section Area using Catia V5 and Ansys 14.5

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Abstract - Leaf spring is a simple form of suspension spring used to absorb vibrations induced during the motion of a vehicle. The automobile industry has shown increased interest in the replacement of steel leaf spring (55 Si 7) with composite leaf spring (E-glass/Epoxy) due to high strength to weight ratio, higher stiffness, high impact energy absorption and lesser stresses. This research is aimed to investigate the suitability of natural and synthetic fiber reinforced hybrid composite material in automobile leaf spring application. By using natural fibers efforts have been made to reduce the cost and weight of leaf spring. In this work an attempt is made to develop a natural and synthetic fiber reinforced hybrid composite material with optimum properties so that it can replace the existing synthetic fiber reinforced composite material in automobile leaf spring. Jute and E-glass woven roving mats are used as reinforcements and epoxy resin is used as the matrix material. The CAD models of Leaf spring are prepared in CATIA V5 and imported in static structural analysis work bench of Ansys 14.5 where finite element analysis (FEA) is performed. The design constraints are stresses and deflections. This study gives a comparative analysis between steel leaf spring and Jute/E glass reinforced Epoxy leaf spring. The hybrid composite leaf spring is found to have lesser weight, lesser cost, lesser stresses and higher stiffness

I. INTRODUCTION

OVER VIEW OF LEAF SPRING: A leaf spring is a long, flat, thin, and flexible piece of spring steel or composite material that resists bending. The basic principles of leaf spring design and assembly are relatively simple, and leaves have been used in various capacities since medieval times. Most heavy duty vehicles today use two sets of leaf springs per solid axle, mounted perpendicularly to the axle and supporting the vehicle's weight. This system requires that each leaf set act as both a spring and a horizontally stable link. Because leaf sets lack rigidity, such a dual-role is only suited for applications where load-bearing capability is more important than precision in suspension response. Older transverse leaf spring arrangements mounted the a single leaf set running parallel to a live axle, but used it both as a suspension link and a spring element in a similar manner to the traditional arrangement. In vehicles with independent suspension and a transverse leaf spring arrangement the leaf is not used to control the wheel's location and acts only as a spring element. In this arrangement double wishbones act to locate the wheel, while a single leaf or leaf set connected to the front or rear sub-frame in the middle of the vehicle and the lower wishbone on each side provides the spring element. In some applications two transverse leaf springs are used on a single axle with each providing separate springing action to each wheel. In the past most transverse leaf springs arrangements used multiple steel elements in a set similar to their traditional longitudinal counterparts, but most modern applications use a composite (generally fiberglass) mono leaf element.

Fig.1 A traditional leaf spring arrangement.

Originally called laminated or carriage spring a leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. It is one of the oldest forms of springing, dating back to medieval times.

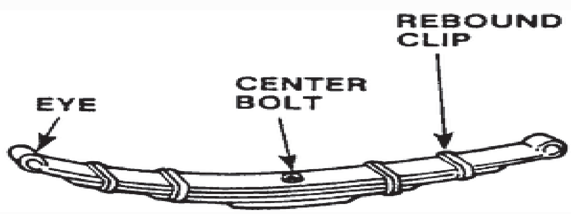


Fig.2 Leaf Spring of Automobiles

Sometimes referred to as a semi-elliptical spring or cart spring, it takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. The center of the arc provides location for the axle, while tie holes are provided at either end for attaching to the vehicle body. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with systematically shorter leaves. Leaf springs can serve locating and to some extent damping as well as springing functions.

II. COMPOSITES

COMPOSITE MATERIALS

The choice of the material for leaf springs depends on both engineering design requirements and economies of the application. A study made on JUTE/E-GLASS/EPOXY reveal that the specific stored energy coefficient (SEC), used as design criterion, is advantageous compared to conventional steel leaf springs. Considerations for fatigue of JUTE/E-GLASS/EPOXY can be grouped under the heading of material, processing, and design.

JUTE/E-GLASS/EPOXY leaf springs are generally designed as a mono-leaf beam. The mono-leaf design is possible with JUTE/E-GLASS/EPOXY, since the material can be designed for high strength as well as good deflection characteristics. JUTE/E-GLASS/EPOXY leaf springs are extensively made using of unidirectional glass fiber because of its good combination of mechanical properties and of its low cost. Fatigue characteristics of composites are different from that of metals. For simple tension unidirectional composites, the fatigue limits are generally of higher percentages of tensile strength. Thus the durability of composite leaf spring is superior to that of conventional leaf springs under fatigue loading.

Unlike the conventional multi-leaf springs, the spring's eyes for composite leaf springs are separately made and joined to the JUTE/E-GLASS/EPOXY leaf spring because of different material are used for spring and eyes. The eyes are made in metal and joined to the composite leaf springs either by adhesive bonding or mechanical fastening. Since the unidirectional JUTE/E-GLASS/EPOXY system is sensitive for fiber discontinuity, the joint design becomes very critical.

Composites consist of two or more materials or material phases that are combined to produce a material that has superior properties to those of its individual constituents. The constituents are combined at a macroscopic level and or not soluble in each other. The main difference between composites, where as in alloys, constituent materials are soluble in each other and form a new material which has different properties from their constituents.

ADVANTAGES OF COMPOSITES OVER THE CONVENTIONAL MATERIALS

- High strength to weight ratio
- High stiffness to weight ratio

- High impact resistance
- Better fatigue resistance
- Improved corrosion resistance
- Good thermal conductivity
- Low coefficient of thermal expansion. As a result, composite structures may exhibit a better dimensional stability over a wide temperature range.

APPLICATIONS OF COMPOSITES

The common applications of composites are extending day by day. Nowadays they are used in medical applications too. The other fields of applications are,

- Automotive: Leaf springs, Drive shafts, clutch plates, engine blocks, push rods, frames, Valve guides, automotive racing brakes.

III. SUSPENSION SYSTEM

The automobile chassis is mounted on the axles, not direct but 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 anybody. All the part, which performs the function of isolating the automobile from the road shocks, is collectively called a suspension system. It includes the springing device used and various mountings for the same.

Broadly speaking, suspension system consists of a spring and a damper. The energy of road shock causes the spring to oscillate. These oscillations are restricted to a reasonable level by the damper which is more commonly called a shock absorber.

Objective of Suspension

- To prevent the road shocks from being transmitted to the vehicle components.
- To safeguard the occupants from road shocks
- To preserve the stability of the vehicle in pitting or rolling, while in motion

IV. SELECTION OF COMPOSITE MATERIAL

Experimental Materials

There are three types of materials employed in this study: 1.] Steel 2.] E-Glass/Epoxy 3.] Jute/E-Glass/Epoxy 55Si7 is the most popular grade of spring steel being used in automobile leaf spring.

Table 1: Mechanical Properties of 55Si7.

Parameter	Young's Modulus	Poisson's Ratio	Tensile Strength	Density
Value	190-210 MPa	0.27-0.30	572.3 MPa	1000 kg/m^3

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. The relationship of the specific strain energy can be expressed as:

$$U = \sigma^2/\rho E$$

Where, σ is the strength, ρ is the density and E is the young's modulus of the spring material. It can be easily observed that material having lower modulus and density will have a greater specific strain energy capacity. Research has indicated that E-Glass/Epoxy has good characteristics for storing specific strain energy as E-glass has lower young's modulus and lower density than steel. Hence, E-Glass/Epoxy is selected as the composite material. In this research work, a natural fiber i.e. Jute is introduced in E-Glass/Epoxy to develop a hybrid composite material which can reduce the weight as well as cost of leaf spring.

Preparation of Composite Laminates

Samples are prepared having 100% glass, 10% jute-90% glass, 20% jute-80% glass, 30% jute-70% glass and 40% jute-60% glass fiber.

Tensile Property Test

Mechanical properties such as tensile strength, Young's modulus, elongation at break and Poisson's ratio are measured by using a universal testing machine with the maximum load capacity 100 KN. Tensile test is Conducted according to test speed for each composition, five measurement are taken and average values of strength, modulus, elongation at break and Poisson's ratio are reported. 100% glass and 20% jute-80% glass compositions both having epoxy as the base matrix are selected for automobile leaf spring application .

Table 2: Mechanical Properties of E-glass/Epoxy.

Parameter	Young's Modulus	Poisson's Ratio	Tensile Strength	Density
Value	24000 MPa	0.3	205 MPa	1520 Kg/mm^3

Table3: MechanicalProperties of Jute/E-glass/Epoxy.

Parameter	Young's Modulus	Poisson's Ratio	Tensile Strength	Density
Value	21000 MPa	0.22	185 MPa	1460 Kg/mm^3

The following methodology is adopted for the present work.

- Present work is related to the comparative study of "55 Si 7 steel and composite leaf spring" Component details.
- The component details is studied and prepared 3-D model in CATIYA V5 software.
- The component is studied for the operation required to convey the different types of loads on it. Design the component in the required shape and dimensions and analyzed.
- Design calculations are carried for the component leaf spring with the help of material properties which are specified by the previous research.
- Analysis work is carried by importing 3-D model into Ansys software. A FEM model of leaf spring, only one leaf is created by using Ansys processor. The material properties loads and boundary conditions are also specified in the Ansys Processor.
- Analysis work is done by applying loads on the leaf spring then the results such as stress, strain, total deformation are obtained.
- The results are compared with material properties of the material used for the component. Then we find that results obtained by using FEM are within the material properties. There we find that the component can withstand for given loads during operation.

Standard Size of Automobile Suspension Spring

Following are the standard sizes for the automobile suspension springs:

Leaf springs are made of various fine grade alloy steel. The most commonly used grades of spring steel are 55 Si 7, 60 Si Cr 7, 50 Cr V4. in India. The chemical composition of spring steel mentioned above is as under in table 4.

Table 4: Chemical Composition of Different Grades

	GRADE	C	Si	Mn	S	P
1	**EN 45A**	0.55-0.65	1.70-2.10	0.70-1.00	0.040 Max	0.040 Max
2	**55 Si7**	0.55-0.6	1.50-1.80	0.70.1.00	0.045 Max	0.045 Max

MODELING OF A LEAF SPRING

Table.5 Design Parameters of Steel Leaf Spring.

The following table shows the specifications of a leaf spring in catia v5

Total Length Of Leaf Spring (Eye to Eye)	1100 mm
Arc Height At Axle Seat	170 mm
Thickness Of Leaf Spring	6 mm
Width Of Leaf Spring	56 mm
Outer Diameter Of Eye	50 mm
Inner Diameter Of Eye	44 mm

V. CATIA

INTRODUCTION TO CATIA

Computer aided three dimensional interactive applications as high end CAD/CAE/CAM tool used worldwide. Catia v5 is developed by Dassault Systems. France is a completely re-engineered next generation family of CAD/CAM/CAE software solutions for product lifecycle management. Through its exceptionally easy to use state of the art user interface CATIA V5 delivers innovative technologies for maximum productivity and creativity from concept to the final product. CATIA V reduces the learning curve as it allows the flexibility of using feature based and parametric designs.

CATIA V5 provides three basic platforms – P1, P2 and P3. P1 is for small and medium sized process oriented companies which wish to grow towards the large scale digitized product definition. P2 is for the advanced design engineering companies that require product, process and resources modeling. P3 is for the high-end design application and is basically for automotive and aerospace industry where high equality surfacing or Class-A surfacing is used for designing. The subject of interpretability offered by CATIA V5 includes receiving legacy data from the other CAD systems and even between its own product data management modules. The real benefit is that the links remain associative. As a result any changes made to this external data are notified and the model can be updated quickly. CATIA V5 serves the basic tasks by providing different workbenches. A workbench is defined as a specific environment consisting of a set of tools which allows the user to perform specific design tasks in a particular area.

FINAL DESIGNED MODEL OF LEAF SPRING IN CATIA V5 FOR 55 SI 7.

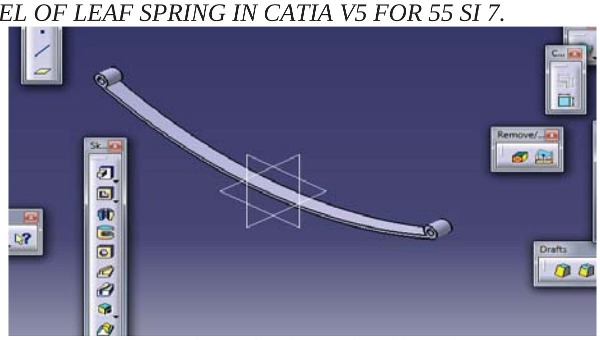


Fig.3 55 si 7 Leaf Spring Designed in Catia v5

VI. FINITE ELEMENT ANALYSIS

FEA: The finite element analysis (finite element method) is a numerical technique for finding approximate solutions of partial differential equations as well as of integral equations. The solution approach is based on either eliminating the differential equation completely (steady state problems) or rendering the partial differential equation into an approximating system of ordinary differential equations, which are then numerically, integrated using standard techniques such as Euler's method etc.

In the finite element method, a structure is broken down into many small simple blocks or elements. The behavior of an individual element can be described with a relatively simple set of equations. Just as the set of elements would be joined together to build the whole structure, the equations describing the behaviors of the individual elements are joined into an extremely large set of equations that describe the behavior of the whole structure.

VII. GENERAL PROCEDURE OF FEA

The following steps summarize the general procedure for finite element analysis.

- STEP 1 - The continuum is a physical body, structure or solid being analyzed. Discretization may be simply described as process by which the given body is subdivided into equivalent system of finite elements...
- STEP 2 - The selection of displacement or temperature models or shape functions representing approximately the actual distribution of the displacement or temperature. The three factors which influence the selection of shape functions are

a. The type and degree of displacement model
b. Displacement magnitudes
c. The requirements to be satisfied which ensuring correct solution.

- STEP 3 - The derivation of the stiffness matrix which consists of the coefficients of the equilibrium equations derived from the geometric and material properties of the element. The stiffness relates the displacement at nodal points to applied forces at nodal points.
- STEP 4 - Assembly of the algebraic equations for the overall discredited continuum includes the assembly of overall stiffness matrix for the entire body from individual element stiffness matrices and the overall global load vector from the elemental load vectors.
- STEP 5 - The algebraic equations assembled in step 4 are solved for unknown displacements by imposing the boundary conditions. In linear equilibrium problems, this is a relatively straightforward application of matrix algebra techniques.
- STEP 6 - In this step, the element strains and stresses are computed from the nodal displacements that are already calculated from step 5.

ADVANTAGES AND LIMITATIONS OF FEA

Planning the analysis is arguably the most important part of any analysis, as it helps to ensure the success of the simulation. Oddly enough, it is usually the one analysis leave out. The purpose of an FEA is to model the behavior of a structure under a system of loads. In order to do so, all influencing factors must be considered and determined whether their effects are considerable or negligible on the much dependent on the level of planning that has been carried out.

FEA is an approximate way of simulation the system behavior. But the results can be quite close to actual testing values. FEA can never replace actual physical testing all the times. This is due to fact, the information required for FEA simulations like material properties emanates from physical testing.

FEA results by themselves can never be taken as complete solution. Usually at least one prototype testing is necessary before the design guided/validated through FEA can be certified.

APPLICATIONS OF FEA

- Structural engineering (analysis of frames, trusses, bridges etc).
- Aircraft engineering (analysis of aero plane wings, different parts of missiles and rockets).
- Heat engineering (analysis on temperature distribution, heat flux etc).

POPULAR FEA SOFTWARES

There are varieties of commercial FEA software available over the market. No single software is supposed to have all the capabilities that can meet the complete simulation requirements of a design. Hence based upon the requirements, some of the firms use one or more FEA software. While some other firms develop their own customized versions of software. Some of the popular commercially available FEA software is as follows.

- Abaqus
- Ansys

VIII. INTRODUCTION TO ANSYS

ANSYS is a general-purpose finite element-modeling package for numerically solving a wide variety of mechanical problems. These problems include: static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems. It enables engineers to perform the following tasks - build computer models or transfer cad models of structures, products, components or system, apply operating loads or other design performance conditions, study physical responses such as stress levels, temperature distributions or electromagnetic fields, optimize a design early in the development process to reduce production costs, carryout prototype testing in environment where it otherwise would be undesirable or impossible.

ADVANTAGES OF ANSYS

ANSYS provides a cost-effective way to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping.

With virtual prototyping techniques, users can iterate various scenarios to optimize the product life before the manufacturing is started. This enables a reduction in the level of risk, and in the cost of ineffective designs. The multifaceted nature of ANSYS also provides a means to ensure that users are able to see the effect of design on the whole behavior of the product, be it electromagnetic, thermal, mechanical etc.

STATIC STRUCTURAL ANALYSIS FOR (55 Si 7) STEEL LEAF SPRING

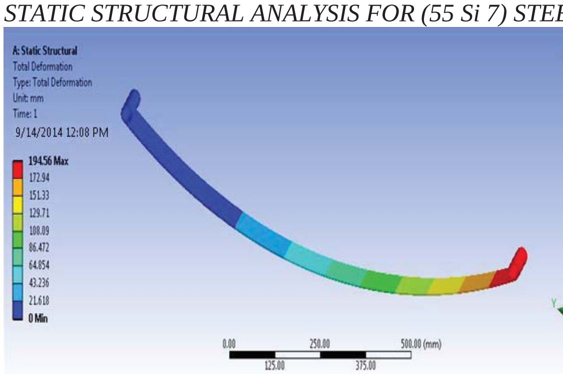


Fig.4 Total deformation 500(N).

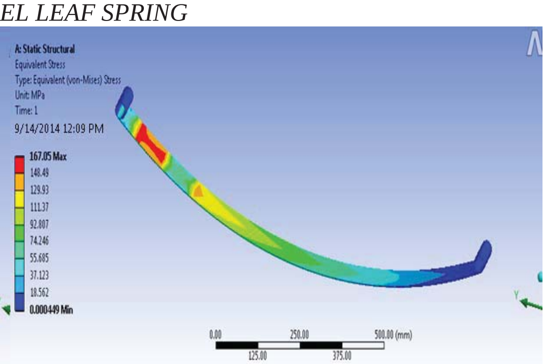


Fig.5 Equivalent Stress 500(N).

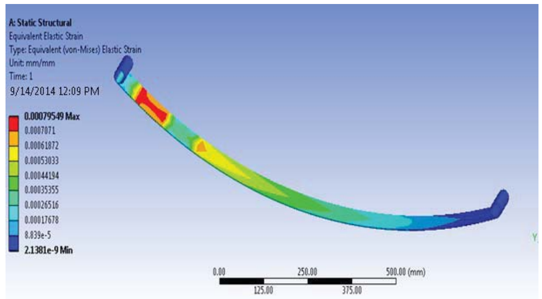


Fig.6 Equivalent Elastic Strain 500(N).

DESIGN PARAMETERS OF COMPOSITE LEAF SPRING.

Table.6 Design Parameters of Composite Leaf Spring.

Total Length Of Leaf Spring (Eye to Eye)		965 mm
Arc Height At Axle Seat		125 mm
Thickness	At Centre	60 mm
	At Ends	10 mm
Width	At Centre	30 mm
	At Ends	45 mm

FINAL DESIGNED MODEL OF LEAF SPRING IN CATIA V5 E-GLASS/EPOXY LEAF SPRING AND JUTE/EGLASS/EPOXY.

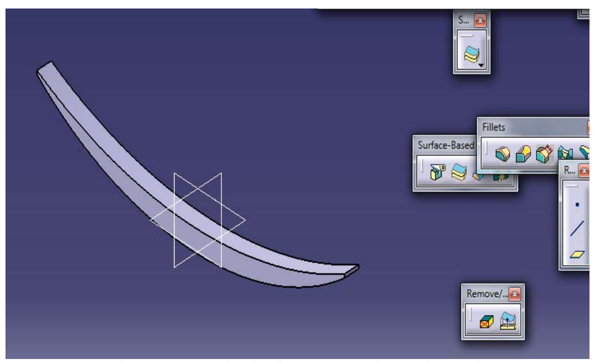


Fig. 7 Composite leaf Spring Designed in Catia

1. By varying the dimensions and considering the composite material large variation of stress, strain and deformation is obtained when compared with 55 si 7 steel.
2. By considering the modified design values the weight of E-glass/Epoxy leaf spring weight 2.8 Kg and Jute/E-glass/Epoxy leaf spring weighs 2 Kg.

IX. STATIC STRUCTURAL ANALYSIS FOR E-GLASS/EPOXY LEAF SPRING.

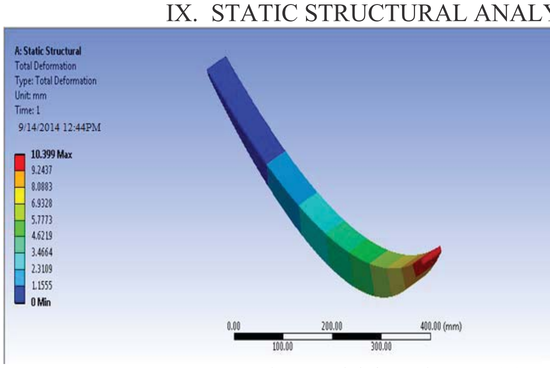


Fig.8 Total deformation 1000(N).

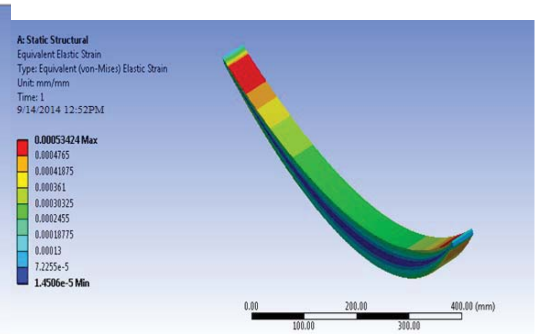


Fig.9 Equivalent Elastic Strain 1000(N)

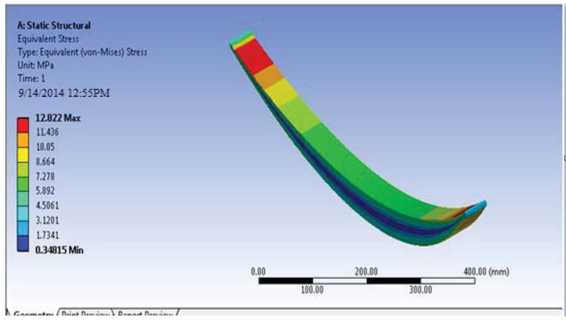


Fig.10 Equivalent Stress 1000(N).

STATIC STRUCTURAL ANALYSIS FOR JUTE/E-GLASS/EPOXY LEAF SPRING.

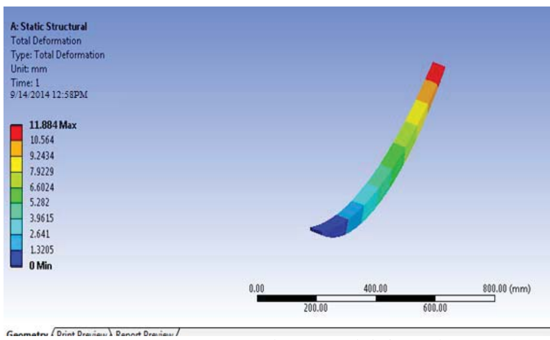


Fig.11 Total deformation 1000(N).

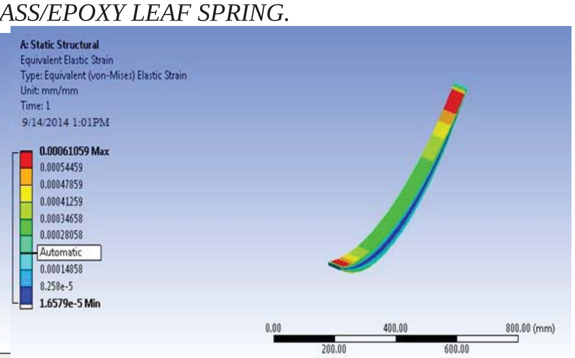


Fig.12 Equivalent Elastic Strain 1000(N).

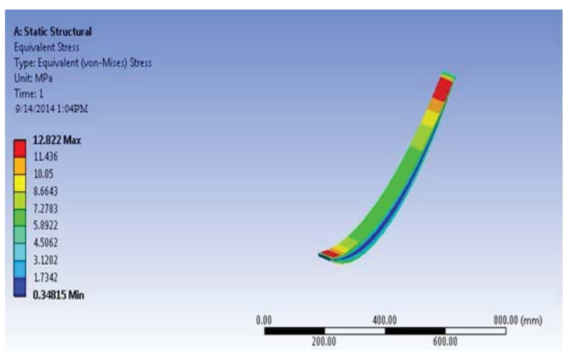


Fig.13 Equivalent Stress 1000(N).

X. RESULTS AND DISCUSSION

THEORITICAL CALCULATIONS.

A semi-elliptical leaf spring may be considered as two cantilever leaf springs, and a full-elliptical leaf spring.

Let

F= force applied at the end of the leaf spring

b = width of each leaf spring

t = thickness of each leaf

n = number of graduated leaves

l = length of the spring

σb = bending stress

Maximum bending movement, M_{max} =F l

M_{max}

Bending stress, $\sigma b = \frac{Mmax}{Z}$,

where $Z = \frac{nbt^2}{6}$ = $\sigma b = \frac{6Fl}{nbt^2}$

$\sigma b = \frac{6X\ 500\ X\ 1049.26}{6\ X\ 86\ X\ 6^2}$ = 260.23 N/mm^2

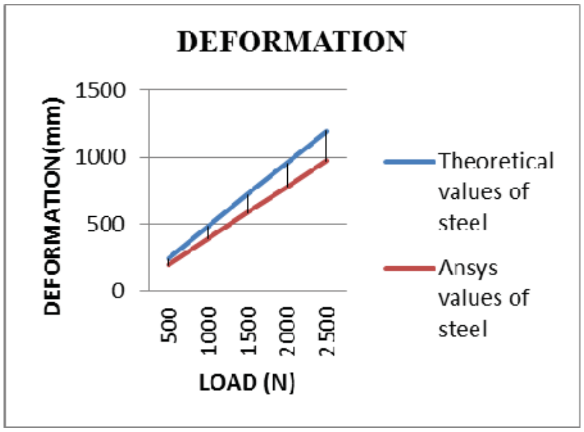
Maximum deflection, $\delta_{max} = \frac{6Fl^3}{Enbt^3}$

$$\delta_{max} = \frac{6X\ 800 X 1049.26^3}{2.1X\ 10^5\ X 6\ X 86\ X 6^3} = 238.75\ mm$$

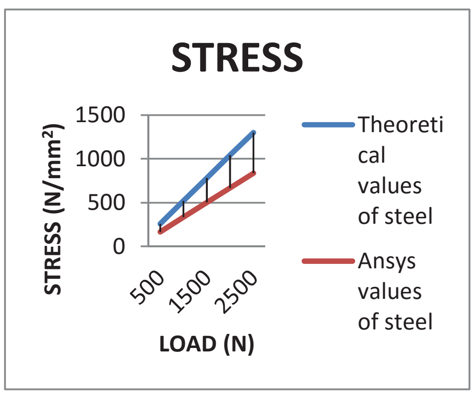
COMPARISON OF 55 SI 7 STEELS WITH THEORETICAL AND SIMULATION RESULTS

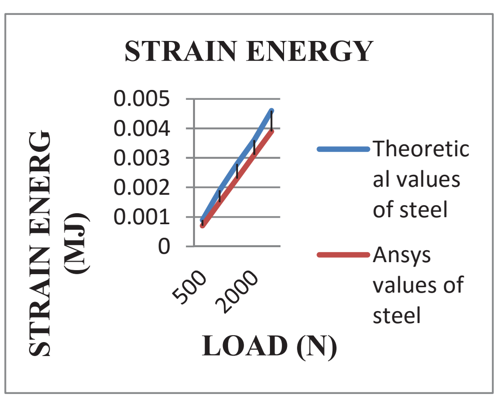
Table.7 Comparison between Theoretical and Simulation results of 55Si7.

	Total deformation (mm)		**Stress (N/mm^2)**		**Strain energy (MJ)**	
LOAD (N)	**Theoretical values of steel**	**Ansys values of steel**	**Theoretical values of steel**	**Ansys values of steel**	**Theoretical values of steel**	**Ansys values of steel**
500	238.75	194.56	260.23	167.05	0.0009	0.0007
1000	477.50	389.12	520.46	334.11	0.0019	0.0015



GRAPH -1 Load Vs Deformation





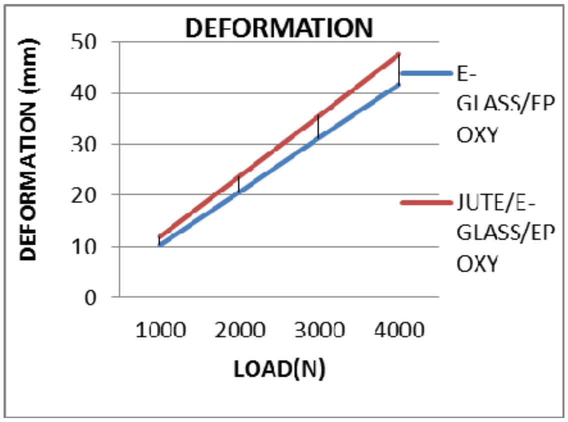
GRAPH -2 indicates Load Vs Stress

GRAPH -3 Load Vs Strain energy

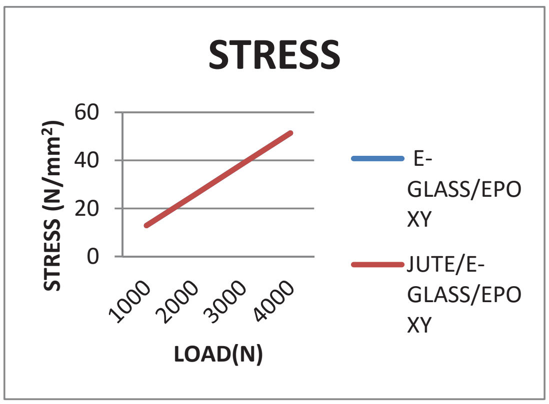
COMPARISON BETWEEN [A](E-GLASS/EPOXY) LEAF SPRING AND [B](JUTE/E-GLASS/EPOXY).

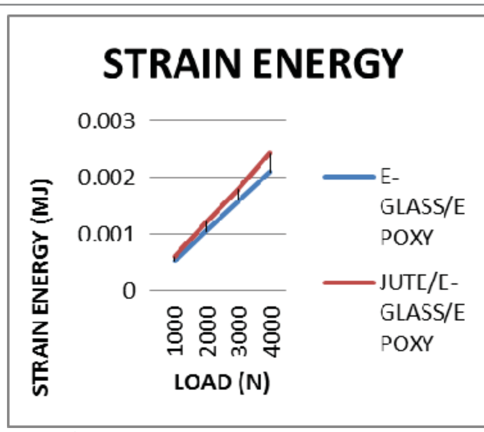
Table.8 Comparison between E-Glass/Epoxy and Jute/E-Glass/Epoxy results.

	Total Deformation(mm)		Stress (N/mm^2)		Strain energy (MJ)	
LOAD (N)	**[A]**	**[B]**	**[A]**	**[B]**	**[A]**	**[B]**
1000	10.39	11.88	12.822	12.822	0.00053	0.00061
2000	20.78	23.76	25.644	25.645	0.00106	0.00122



GRAPH -4 Load Vs Deformation.

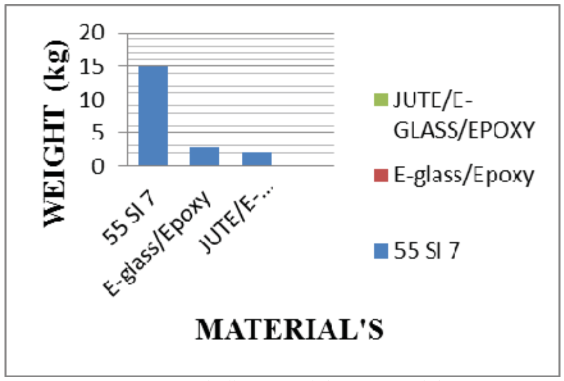




GRAPH -5 Load Vs Stress GRAPH -6 Load Vs Strain energy

COMPARISON OF WEIGHTS

Bar- Chart drawn for the comparison of weight of both steel and composite leaf springs. The bar chart drawn below shows the comparisons in leaf spring weight (Kg) in case of steel and composite material. From this comparison of bar chart it is easily observed that the weight reduction in leaf spring. For steel leaf spring weight is 15kg and for composite leaf springs it is 2.8 & 2 kgs.



GRAPH -7 indicates Weight Vs Material

XI. CONCLUSION

The 3-D modeling of both steel and composite leaf spring is done and analyzed A comparative study has been made between composite and steel leaf spring with respect to Deflection , strain energy and stresses. From the results.

1. This research work provides optimum values for design variables (leaf spring thickness and width) of hybrid composite leaf spring by using finite element Analysis.
2. Weight can be reduced by 55% if steel leaf spring is replaced by Jute/E-Glass/Epoxy hybrid composite leaf spring. Weight reduction reduces the fuel consumption of the vehicle.
3. At various loading conditions, hybrid composite leaf spring is found to have lesser stresses and deflections as compared to conventional steel leaf spring.
4. Jute/E-glass/Epoxy hybrid composite has higher elastic strain energy storage capacity than both steel and E-glass/Epoxy composite because it has lower young's modulus and lower density as compared to both. Hence hybrid composite leaf spring can absorb more energy which leads to good comfortable riding.
5. Jute/E-glass/Epoxy hybrid composite leaf spring is found to be more economical than E-glass/Epoxy composite leaf spring as the cost of jute fiber is very much less as compared to E-glass fiber and it is abundantly available in nature.

XII. FUTURE SCOPE

The present study can be extended by reducing more weight and also deflections by designing and fabricating a variable width and thickness leaf spring.

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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