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DESIGN AND EXPERIMENTAL ANALYSIS OF COMPOSITE LEAF SPRING USING ANSYS

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ABSTRACT
Reducing weight while increasing or maintaining strength of products is getting to be highly important research issue in this modern world. Composite materials are one of the material families which are attracting researchers and being solutions of such issue. In this paper we describe designand analysis of composite leaf spring. The objective is to compare the stressesand weight saving of composite leaf spring with that of steel leaf spring. The design constraint is stiffness. The Automobile Industry has great interest for replacement of steel leaf spring with that of composite leaf spring, since the composite materials has high strength to weight ratio, good corrosion resistance. The material selected was glass fiber reinforced polymer (E glass/epoxy), carbon epoxy and graphite epoxy is used against conventional steel. The design parameters were selected and analyzed with the objective ofminimizing weight of the composite leaf spring as compared to the steel leaf spring. The leaf spring was modelled in CATIA V5 and the analysis was doneusing ANSYS 14.0 software.
Keywords: Composite materials, design, stiffness, weight ratio, corrosion resistance.

Keywords: smart farming, Artificial intelligence, Internet of Things, sensors.

Introduction
Now a days the fuel efficiency and emission gas regulation of automobiles are two important issues. To fulfill this problem the automobileindustries are trying to make new vehicle which can provide high efficiencywith low cost. The best way to increase the fuel efficiency is to reduce the weight of the automobile. The weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The achievement of weight reduction with adequate improvement of mechanical properties has made composite a verygood replacement material for conventional steel. In automobile, one of its components which can be easily replaced is leaf spring. A leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. The suspension of leaf spring is the area which needs to focus to improve the suspensions of the vehicle for comfort ride. The suspension leafspring is one of the potential items for weight reduction in automobile as it accounts for 10 to 20% of unstrung weight.
It is well known that springs are designed to absorb shocks. So the strainenergy of the material becomes a major factor in designing the springs. India is acountry with more than one billion people, require vehicle to move anywhere around the country for their personal and transportation purpose. We have personally seen and observed that vehicle having no smoothed suspension or comfort ride create the tiredness to the people and more especially to driversof car who is the life of passenger.
The relationship of specific strain energy can be expressed as

$$U = \frac{1}{2} * \frac{\sigma^2}{\rho * E}$$

It can be easily observed that material having lower density and modulus will have a greater specific strain energy capacity. Thus composite material offer high strength and light weight. In this work, leaf spring of automobile vehicle is Mahindra “Model-Commander 650di” car is considered for further investigation. The suspension quality can be improved by minimizing the vertical vibrations, impacts and bumps due to road irregularities which create the comfortable ride.

Fig. 1 A Traditional Leaf Spring Arrangement

A leaf spring can either be attached directly to the frame at both ends orattached directly at one end, usually the front, with the other end attached through a shackle, a short swinging arm. The shackle takes up the tendency ofthe leaf spring to elongate when compressed and thus makes for softer springiness. Some springs terminated in a concave end, called a spoon end (seldom used now), to carry a swiveling member.

1.1.2 Fatigue

In narrow sense, the term fatigue of materials and structural components means damage and damage due to cyclic, repeatedly applied stresses. In a widesense, it includes a large number of phenomena of delayed damage and fractureunder loads and environmental conditions. Plastic deformations are small and localized in the vicinity of the crack tipwhile the main part of the body is deformed elastically, then one has high-cyclefatigue. If the cyclic loading is accompanied by plastic deformation in the bulk of the body, then one has a low-cycle fatigue. Usually we say low-cycle fatigueif the cycle number up to the initiation of a visible crack or until final fracture isbelow 104 or 5.104 cycles.

In material science, fatigue is the progressive, localized, and permanent structural damage that occurs when a material is subjected to cyclic or fluctuating strains at nominal stresses that have maximum values less than (often much less than) the static yield strength of the material. The resulting stress maybe below the ultimate tensile stress, or even the yield stress of the material, yet still cause catastrophic failure. A practical example of low-cycle fatigue would be the bending of a paperclip. A metal paperclip can be bent past its yield pointwithout breaking, but repeated bending in the same section of wire will cause material to fail.

1.1.3 Fatigue Strength

Fatigue strength is defined as the maximum stress that can be endured for a specified number of cycles without failure. Low cycle fatigue strength approaches the static strength. When the cycle number exceeds to one limit, thefatigue strength falls to fraction of the static strength. The fatigue strength is thevalue of the alternating stress that results in failure by fracture a specific numberof cycles of load application

The specimens are machined with shape characteristics which maximize the fatigue life of a metal, and are highly polished to provide the surface characteristics which enable the best fatigue life. A single test consist of applying a known, constant bending stress to a round sample of the material, and rotating the sample around the bending stress axis until it fails. As the sample rotates, thestress applied to any fiber on the outside surface of the sample varies from maximum-tensile to zero to maximum compressive and back.

1.1.4 Fatigue Failure

Failure is one of most important aspects of material behavior because it is directly influent the selection of material for certain application, the method of manufacturing and service life of component. The majority of engineering failures are caused by fatigue. Fatigue failure is defined as the tendency of a material to fracture by means of progressive brittle cracking under repeated alternating or cyclic stresses of intensity considerably below the normal strength.

A good example of fatigue failure is breaking a thin steel rod or wire withyour hands after bending it back and forth several times in the same place. Another example is an unbalanced pump impeller resulting in vibrations that cancause fatigue failure.

Suppose that a particular specimen is being fatigue tested. Now suppose the fatigue test is halted after 20% to 25% of the expected life of the specimen, andthe surface condition is restored to its original state. Now the fatigue test is resumed at the same stress level as before. The life of the part will be considerably longer than expected. If that process is repeated several times, the life of the part may be extended by several hundred percent, limited only by theavailable cross section of the specimen. That proves fatigue failures originate atthe surface of a component.

Fatigue failure is also due to crack formation and propagation. A fatigue crack will typically initiate at a discontinuity in the material where the cyclic stress is a maximum. Discontinuities can arise because of:

- Design of rapid changes in cross-section, keyways, holes, etc. where the cyclic stress concentrations occur.
- Element that roll and/or slide each other (bearings, gears, cams) under high contact pressure, developing concentrated subsurface contact surfaces that can cause pitting from after many cycles of the load.
- Carelessness in locations of stamp marks, tool marks, scratches, and burrs; poor joint design; improper assembly; and other fabrications faults.

3 Compositions of the material itself as processed by rolling, forging, casting, extrusion, drawing and heat treatment. Microscopic and sub-microscopic surface and subsurface discontinuities arise. Fatigue fracture typically occursin material of basically brittle nature. External or internal cracks develop at pre-existing flaws or fault of defects in the material; these cracks then propagate andeventually they lead to total failure of part. The fracture surface in fatigue is generally characterized by the term “beach marks”.

1.1.5 Materials for Leaf Spring

The material used for leaf springs 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 products has greater strength and therefore greater loadcapacity, greater range of deflection and better fatigue properties.

1.1.6 Carbon/Graphite fibers

Their advantages include high specific strength and modulus, low coefficient ofthermal expansion and high fatigue strength. Graphite, when used alone has lowimpact resistance. Its drawbacks include high cost, low impact resistance and high electrical conductivity.

1.1.7 Glass Fibbers

The main advantage of Glass fiber over others is its low cost. It has high strength, high chemical resistance and good insulating properties. The disadvantages are low elastic modulus poor adhesion to polymers, low fatigue strength and high density, which increase leaf spring weight and size. Also crack detection becomes difficult.

1.1.8 Composite Materials

A composite material is made by combining two or more materials –oftenones that have very different properties. The two materials work together to give the composite unique properties. However, within the composite you can easily tell the different materials apart as they do not dissolve

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or blend into each other.
1.1.9 Composite Leaf Springs
Composites are well suited for leaf-spring applications due to their high strength-to-weight ratio, fatigue resistance and natural frequency. Internal damping in the composite material leads to better vibration energy absorption within the material, resulting in reduced transmission of vibration noise to neighboring structures.The biggest benefit, however, is mass reduction: Composite leaf springs are up to five times more durable than a steel spring, so switched to a glass-reinforced epoxy composite transverse leaf spring, a mono-leaf composite spring, weighing 8 lb/3.7 kg, replaced a ten-leaf steel system that weighed 41 lb/18.6 kg. The leaf spring was transverse-mounted; that is,it ran across the car‟s width at each axle. This eliminated the coil springs that situp high in a spring pocket on the frame. Thus, the car can sit lower to the ground, which improves car handling.
1.1.10 Higher Speed, Greater Volume
To date, commercial glass - and carbon-reinforced composite leaf springs have been limited to low-volume production models. "When resins were firstbeing used in the automotive industry, epoxy systems already proven in the aerospace industry were the first to be selected," explains Scott Simmons, business development specialist for chassis, Henkel Corp. (Madison Heights, Mich.). "While these epoxy systems provide a very high-performing part, the prepare manufacturing process primarily employed with these resin systems is better suited for the low-volume production associated with aerospace."which, for purposes of quality assurance to high aerospace standards, necessarily involved slow and carefully controlled applications of temperature and pressure. However, much research has gone intoexpediting the production process through the use of faster melding processes and the development and use of suitably fast-reacting resin systems. These emerging systems show promise for economical mass production of composite leaf springs. These run parallel to the length of the vehicle, providing suspensionas an integrated part of the wheel guidance system.
Leaf springs are mainly used in suspension systems to absorb shock loadsin automobiles like light motor vehicles, heavy duty trucks and in rail systems. It carries lateral loads, brake torque, driving torque in addition to shock absorbing. 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

Fig. 2 New Generation Composite Leaf Springs

2. Problem Definition
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 un-sprungweight. The introduction of composites helps in designing a better suspension system with better ride quality if it can be achieved without much increase in cost and decrease in quality and reliability. The relationship of the specific strain energy can be expressed as it is well known that springs, are designed to absorband store energy and then release it slowly. Ability to store and absorb more amount of strain energy ensures the comfortable suspension

system. Hence, thestrain energy of the material becomes a major factor in designing the springs.

3. Design of Leaf Spring
3.1 Dimensions of Leaf Spring
The leaf spring is main element of the suspension system. It can control for the wheels during acceleration, braking and turning, general movement caused by the road undulations. Leaf springs are designed in two methods: multi-leaf and mono leaf. The multi-leaf spring is made of several steel plates of different lengths stacked together. During normal operation, the spring compresses to absorb road shock. An example of a mono-leaf spring is the tapered leaf spring. The leaf is thick in the middle and tapers towards the two ends. Many of these leaf springs are made of composite material, while others are made of steel. In most cases leaf springs are used in pairs mounted longitudinally (front and back). However, there is an increasing number of vehicle manufacturers using single transverse (side to side) mounted leaf springautomobile suspension system at the rear side and are still in use for commercial vehicles suspension system. It consists of a number of steel strips or leaves placed on the top of each other and then clamped together. The type of application and load carried determines the length and number of leaves. Thetop leaf is called as the main leaf and the ends of the leaf are rolled to form theeye of the spring. This is for attachment to the vehicle chassis or body. The spring eye allows movement about the shackle and pin at the rear.
Three types of leaf springs are:

- Laminated or Multi-leaf springs.
- Single or Mono-leaf springs.
- Tapered leaf springs.

The third type of leaf spring is the combination of the above two. The multi-leaf springs are commonly used in the mobile suspension system at the rear side and are still in use for commercial vehicles suspension system. Itconsists of a number of steel strips or leaves placed on the top of each other and then clamped together. The type of application and load carried determinesthe length and number of leaves. The top leaf is called as the main leaf and theends of the leaf are rolled to form the eye of the spring. This is for attachment to the vehicle chassis or body. The spring eye allows movement about the shackle and pin at the rear.

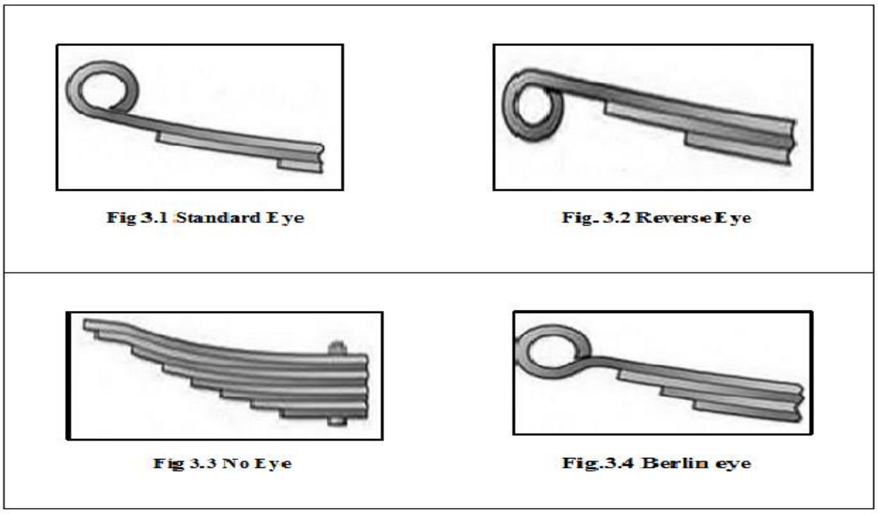


Fig 3.1 Standard Eye
Fig. 3.2 Reverse Eye
Fig 3.3 No Eye
Fig.3.4 Berlin eye

Fig.3 Different Types of Eyes Used In Leaf Spring

Conventional design methods of leaf springs are largely based on the application of empirical and semi-empirical rules along with the use of availableinformation in the existing literature. The functions of springs are absorbing energy and release this energy according to the desired functions to be performed. So leaf springs design depends on load carrying capacity and deflection. Hence the Mahindra "Model-

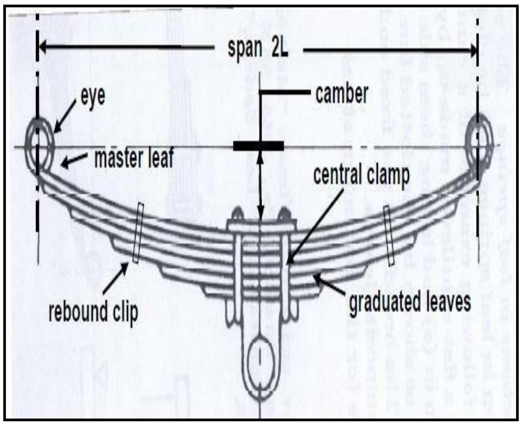
Commander 650di" is considering for design of leaf spring. Basic data of Mahindra pickup leaf spring

Table.1 Mahindra "Model-Commander 650di"

Sl.No	Description		Specifications
1.	Gross vehicle weight	:	2150 kg
2.	Unstrung weight	:	240 kg
3.	Total sprung weight	:	1910 kg
4.	Factor of safety	:	1.4
5.	Total weight	:	26740 N
6.	Total length of the spring (Eye to Eye)	:	1120 mm
7.	No of full length leaves(n_f)	:	1
8.	Thickness of leaf (t)	:	5 mm
9.	Width of the leaf spring (b)	:	50 mm
10.	Total load	:	500 N
11.	BHN = 420 – 430 HB	:	hardened and tempered

Since the vehicle is 4-wheeler, a single leaf spring corresponding to one of thewheels takes up one fourth of the total weight F= 6685

Fig. 4 Terminology of Leaf Spring



4. Modelling of Leaf Spring

Initially CATIA name is an abbreviation for Computer Aided Three- dimensional Interactive Application .The French Dassault Systems is the parent company and IBM participates in the software's and marketing, and catia is invades broad industrial sectors, and has been explained in the previous post position of CATIA between 3d modeling software programs.

CAM (Computer Aided Manufacturing)

CAE (Computer Aided Engineering)

4.1 CATIA ModulesSketcher

This module is responsible for the implementation of two-dimensionalshapes; in preparation for make three-dimensional commands on it.

4.1.1 Part Design

This module is responsible for converting two-dimensional graphics to three dimensional objects which is most famous in Catia and is closely linked with sketcher module. The part design Module it is considered from most important modules, that used by the designer to get the additional advantage from cad programs, which is stereotaxic drawing or three-dimensional drawing.

4.1.2 Wireframes and Surface Design

With this module surfaces can be drawing with zero size and weight and has its uses in the aerospace, automotive, ships and Mold Design.

4.1.3 Generative Sheet Metal Design

This module is responsible of converting two-dimensional graphics to thinsheets or walls having a particular ratio between thickness and its radius. **Assembly** This module is responsible for assembling the parts previously produced in Part Design, and it is most important for those who work in the field of machinery design or design in general, because it is the one who shows the inter-relationships between the parts of the machine or any mechanical establishment. This module is responsible, for converting what you see on the screen to standard engineering drawings can be traded in the workshop for manufacturingor save them for documentation.

4.1.4 Sketcher

This module is responsible for the implementation of two-dimensional shapes; in preparation for make a three-dimensional command on it.

4.1.5 Profile Toolbar

The Profile toolbar contains 2D geometry commands. These geometries range from the very simple (point, rectangle, etc...) to the very complex (splines, conics, etc...). The Profile toolbar contains many sub-toolbars. Most of these sub-toolbars contain different options for creating the same geometry. For example, you can create a simple line, a line defined by two tangent points, or a line that is perpendicular to a surface. Profile toolbar Reading from left to right,the Profile toolbar contain the following commands.

4.1.6 Constraint Toolbar

Constraints can either be dimensional or geometrical. Dimensional constraints are used to constrain the length of an element, the radius or diameterof an arc or circle, and the distance or angle between elements. Geometrical constraints are used to constrain the orientation of one element relative to another. For example, two elements may be constrained to be perpendicular to each other. Other common geometrical constraints include parallel, tangent, coincident, concentric, etc... Reading from left to right:

5. Part Design

This module is responsible for converting two-dimensional graphics to three-dimensional objects which is most famous in Catia and is closely linked with sketcher module. The part design Module it is considered from most important modules that used by the designer to get the additional advantage from cad programs, which stereo toxic drawing or three-dimensional is drawing.

5.1 Patterns

Generally there are 3 types of patterns, which are:

- Rectangular Pattern
- Circular Pattern
- User defined Pattern

With this module surfaces can be drawing with zero size and weight and has itsuses in the aerospace, automotive, ships and Mold Design.

Toolbars in Wire-Frame and Surface Design

Surface Toolbar

Operation Toolbar

Wire-Frame Toolbar

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6. CATIA Design Models

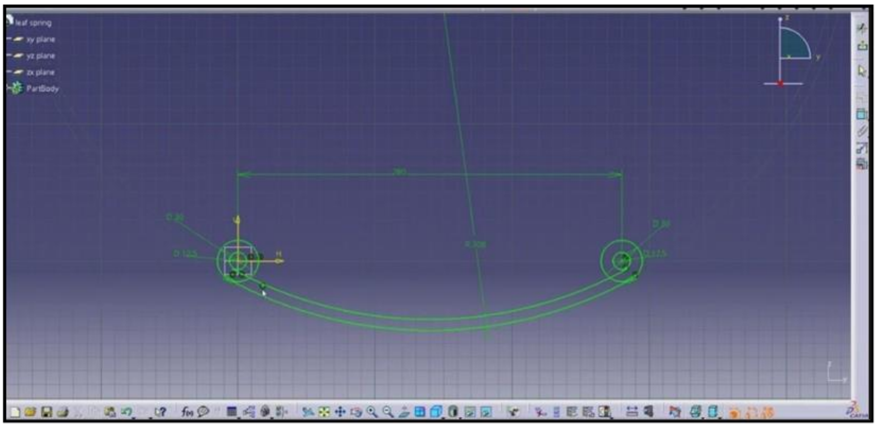

Fig. 5 Wire Model of Master Leaf Spring

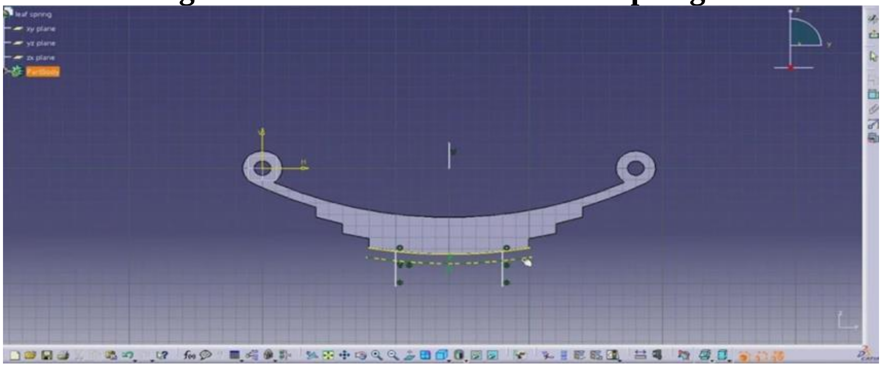

Fig. 6 Solid Model of Master Leaf Spring

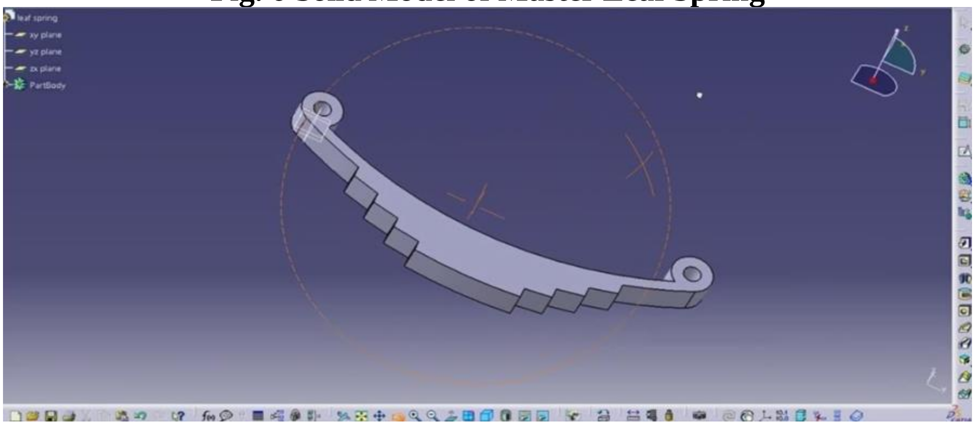

Fig.7 Solid Model of Master Leaf Spring

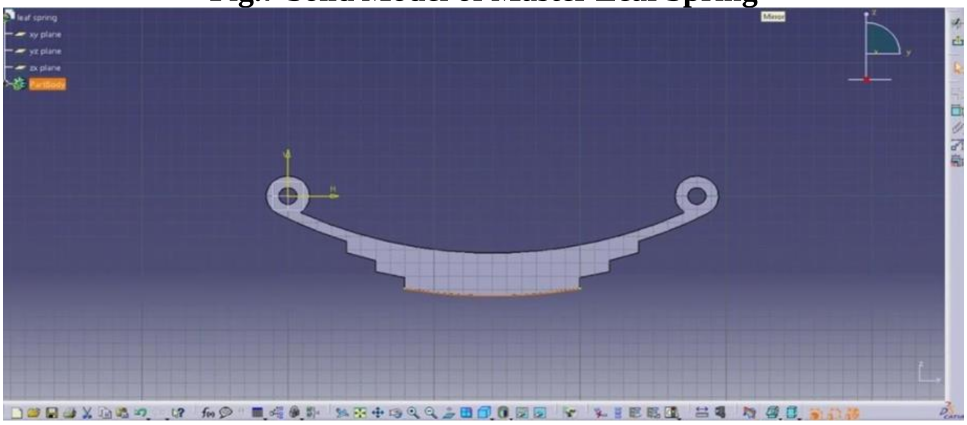

Fig.8 Solid Model of Master Leaf Spring

7.1 ANSYS Process

The process of performing ANSYS can be broken down into three main steps.

7.1.2 Pre-Processing

This step is most important in analysis of leaf spring. Any modeling software can be used for modeling of geometry and can be shifted to other simulation software for analysis purpose. After mesh generation (gridgeneration) is the process of subdividing a region to be modeled into a set of small elements. Meshing is the method to define and breaking up the model intosmall elements. In general a finite element model is defined by a mesh network,which is made up of the geometric arrangement of elements and nodes. Nodes represent points at which features such as displacements are calculated. Elementsare bounded by set of nodes, and define localized mass and stiffness properties of the model. Elements are also defined by the number of mesh, which allowed reference to be made to corresponding deflections, stresses at specific model location. The common type of mesh element used in ANSYS solver is hexahedral, tetrahedral and brick Solver During preprocessing user has to work hard while solution step is the turnof computer to do the job. User has to just click on solve icon. Internally softwarecarries out matrix formations, inversion, multiplication & solution for unknown.

E.g. Displacement & then find strain & stress for static analysis.

7.1.3 Post-Processing

The final step in ANSYS is Post-processing, during which the ANSYS results are analyzed. However, the real value of ANSYS simulation is frequentlyfound in its ability to provide accurate predictions of integrated quantities such as find displacement and stresses. Post processing is viewing results, verifications and conclusions, thinking about what steps could be taken to improve the design.

7.1.4 Assumptions

- Software to be used for ANSYS 14.0
- Model simplification for FEA.
- Meshing size is limited to computer compatibilities.
- Static analysis is considered.

8. Static Analysis of Composite Leaf Spring

As mentioned earlier, the ability to absorb and store more amount of energyensures the comfortable option of a suspension system. However, the problem of heavy weight of spring is still persistent. This can be remedied by introducing composite material, in a place of steel in the conventional leaf spring. Researchhas indicated that the results of E-glass/epoxy, carbon/epoxy and

Graphite/epoxywas found with good characteristics for storing strain energy. So, a virtual model of leaf spring was created in ANSYS workbench and then material is assigned to the model. These results can be used for comparison with the steel leaf spring.

1. Create the model of composite leaf spring in ANSYS Workbench 14.0 static structural module for static analysis.
2. Create leaf spring material E-glass/epoxy.
3. Assign materials to mono leaf spring Create meshing of leaf spring
4. This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of the structure.
5. The mesh has been generated automatically.
6. Apply boundary conditions and loading condition
7. Run analysis and Get results

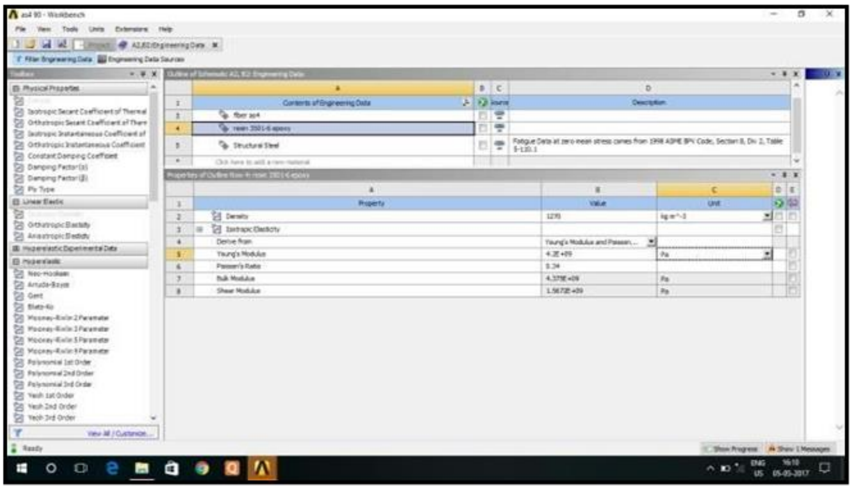

Fig.9 Defining materials in ANSYS

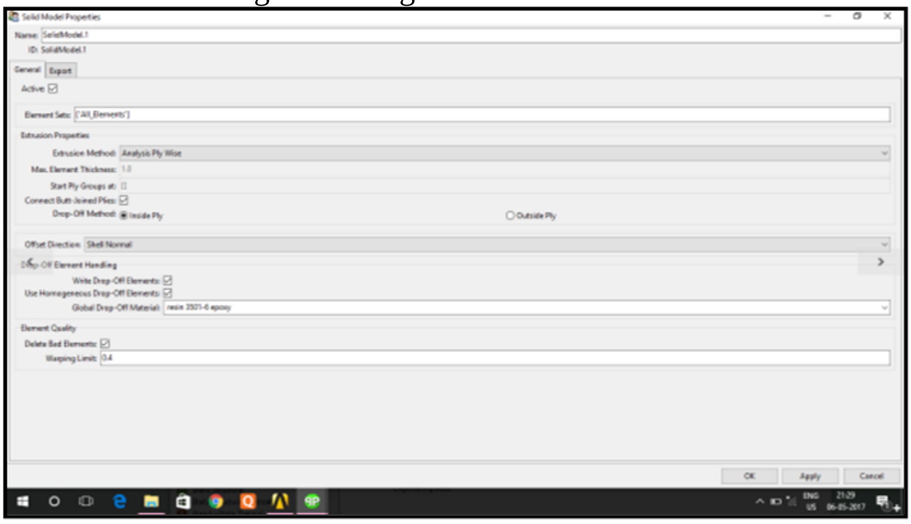

Fig.10 Defining materials in ANSYS

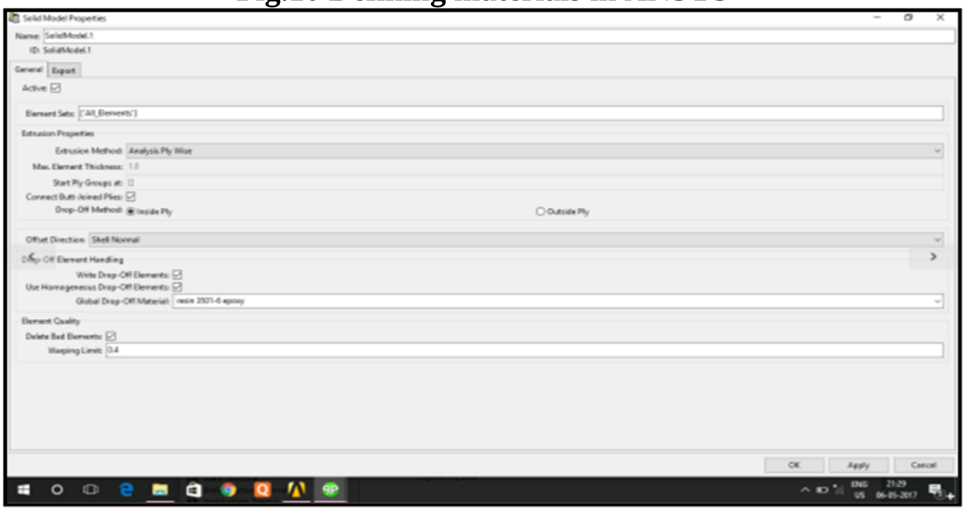

Fig.11 applying materials at mono leaf spring

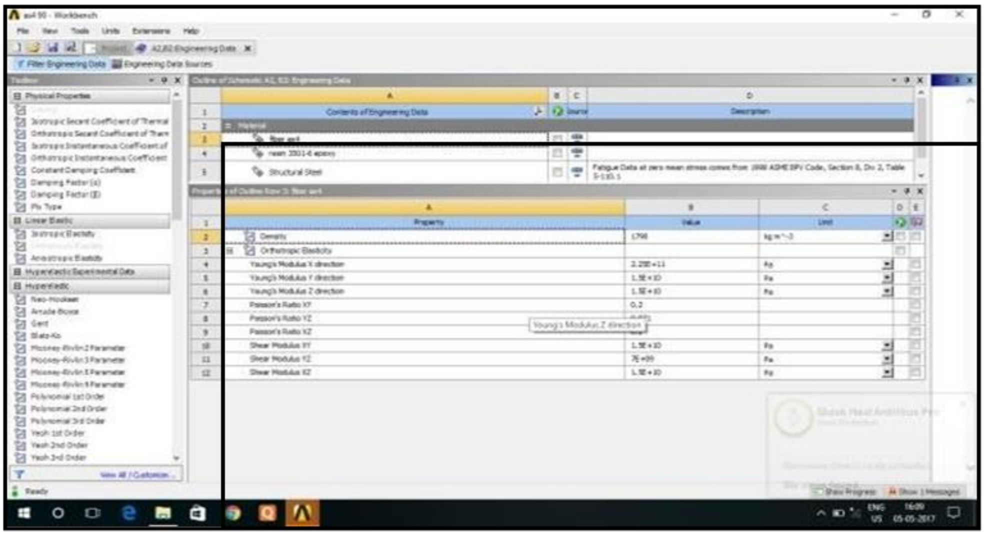

Fig.12 applying materials at mono leaf spring

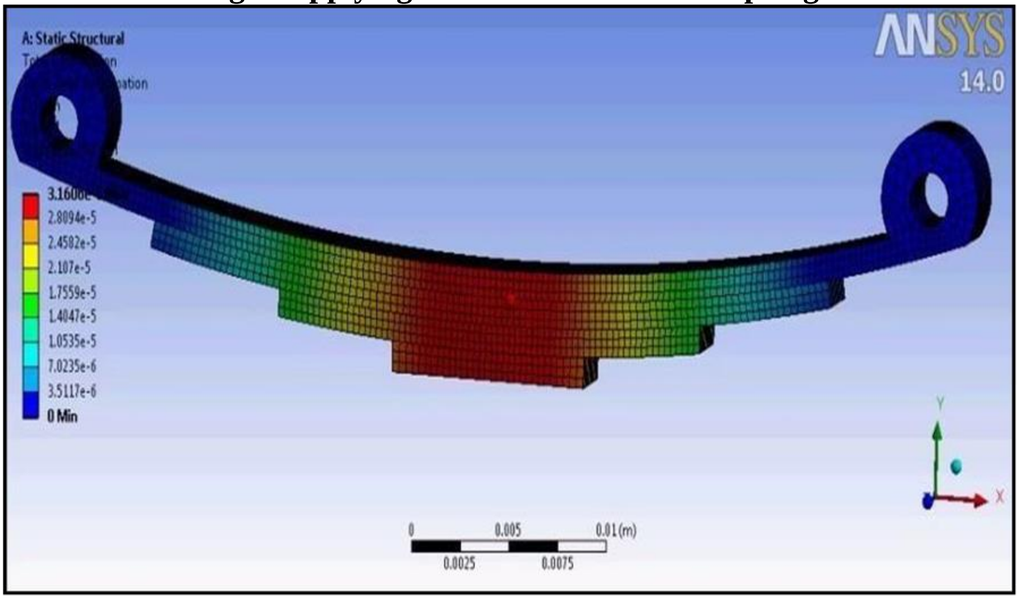

Fig.13 Von– misses stresses of E-Glass/Epoxy leaf spring

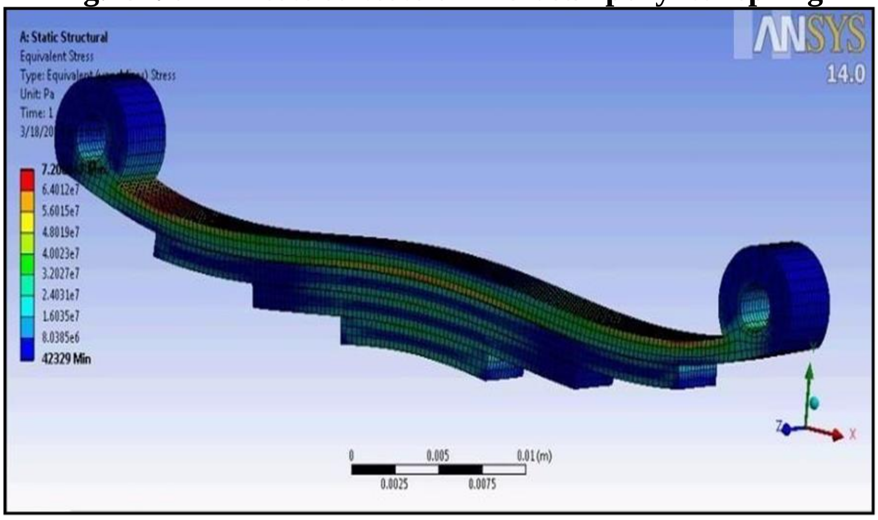

Fig.14 Von– misses stresses of Graphite/Epoxy leaf spring

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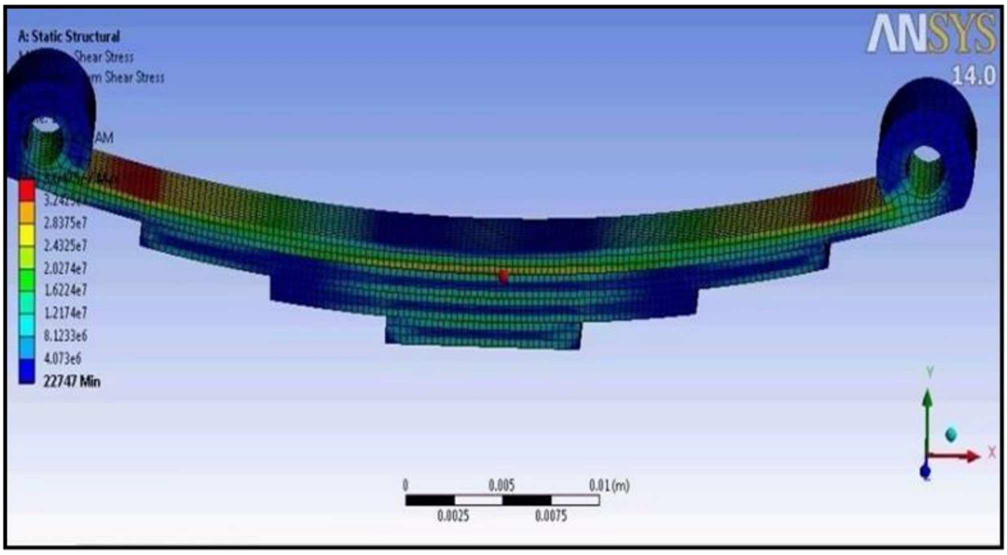

Fig.15 Von– misses stresses of Carbon/Epoxy leaf spring

Static analysis has been performed using ANSYS 14.0, figure 5.3 to 5.5 shows the vanishes stresses plot for composite leaf springs. In the present work, a steel leaf spring was replaced by a mono composite leaf spring due to high strength to weight ratio for the same load carrying capacity and stiffness. The dimensions of a leaf spring of a light weight vehicle are chosen and modeled using auto CATIA and simulation is performed using ANSYS 14.0. As the leafspring is symmetrical about the axis, only half part of the spring is modeled by considering it as a cantilever beam. Analysis has been performed by using ANSYS by applying the boundary conditions and the load. The boundary conditions are UY, UZ at the front eye end and UX, UZ in the middle. A uniformly distributed load of 67N/mm was applied over the ineffective length of the leaf spring in the Y-direction. Later a mono composite leaf spring of uniformthickness and width was modeled so as to obtain the same stiffness as that of steel leaf spring. Three different composite materials have been used for analysis of mono-composite leaf spring. They are E-glass/epoxy, Graphite/epoxy and carbon/epoxy. The results from the plots tabled below.

Table.2 Load and stresses for different material condition.

Load (N)	E-Glass (Stress, MPa)	Graphite (Stress MPa)	Carbon (Stress MPa)
50	100.51	425.1	185.78
60	124.3	505.24	238.2
70	156	598.36	286.85
80	170.54	685.24	310.29

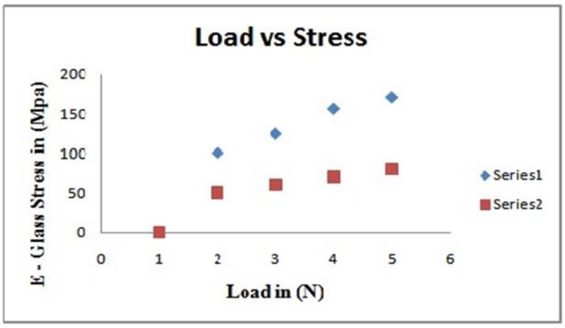

Fig.16 Von– misses stresses of E – Glass vs. Stress acting

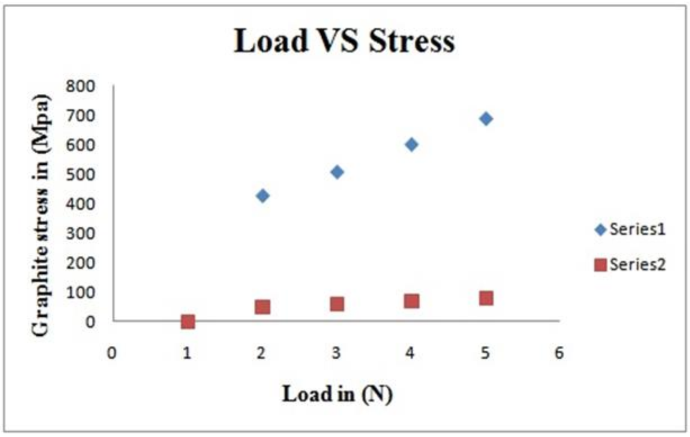

Fig.17 Von– misses stresses of Graphite vs. Stress acting

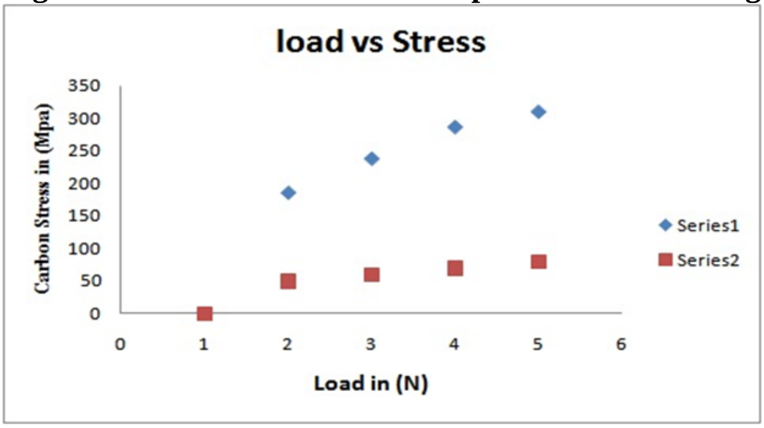

Fig.18 Von– misses stresses of Carbon vs. Stress acting

Table.3 Displacement and stresses for same loading condition.

Materials	Displacement (mm)	Stress (M Pa)
E-glass/Epoxy	16.84	170.54
Graphite/Epoxy	16.25	685.24
Carbon/Epoxy	17.58	310.29

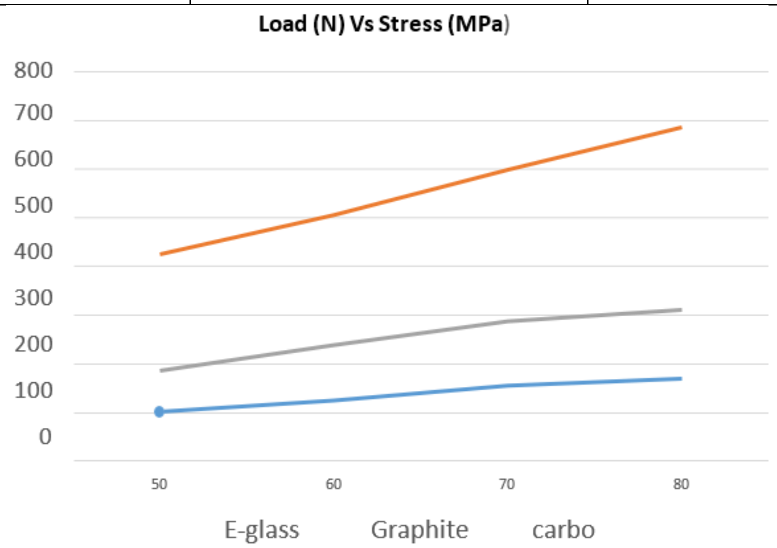

Fig.19 Load and Stress Curve for Different Composite Materials

9. Conclusion

As reducing weight and increasing strength of products are high research demands in the world, composite materials are getting to be up to themark of satisfying these demands. In this paper reducing weight of vehicles and increasing the strength of their spare parts is considered. As leaf spring contributes considerable amount of weight to the vehicle and needs to be strong enough, a single composite leaf spring is designed and it is shown thatthe resulting design and simulation stresses are much below the strength properties of the material satisfying the maximum stress failure criterion.

From the static analysis results already it is found that there is a maximum displacement of 10.16mm in the steel leaf spring and the corresponding displacements in our composite material for E-glass / epoxy, graphite/epoxy, and carbon/epoxy are 16.84 mm, 16.25 mm and 17.58 mm. And all the values are below the camber length for a given uniformly distributed load 87 N/mm over the ineffective length.

From the static analysis results, already we see that the von-mises stressin the steel is 453.92 MPa and the coreesponding von-mises stress for our composite material in E-glass/epoxy, Graphite/epoxy and Carbon/epoxy is to be found as 170.54 MPa, 685.24 MPa and 310.29 MPa respectively.

Among the three composite leaf springs, only graphite/epoxy compositeleaf spring has higher stresses than the steel leaf spring. E-glass/epoxy composite leaf spring can be suggested for replacing the steel leaf spring fromstress and stiffness point of view.

10. References

[1]. M.Venkateshan , D.Helmen Devraj, “design and analysis of leaf spring in light vehicles”, IJMER 2249-6645 Vol.2, Issue.1,pp.213-218, Jan-Feb 2012.

[2]. R.S.Khurmi and J.K.Gupta Machine Design chapter 23.

[3]. U. S. Ramakant & K. Sowjanya, “Design and analysis of automotive multileaf springs using composite material”, IJMPERD 2249-6890 Vol. 3, Issue 1,pp.155-162, March 2013,

[4]. Rajendran I., Vijayarangan S., “Design and Analysis of a Composite LeafSpring”Journal of Institute of Engineers, India ,vol.-8,2-2002

[5]. Dakshraj Kothari,Rajendra Prasad Sahu and Rajesh Satankar Comparisonof Performance of Two Leaf Spring Steels Used For Light Passenger Vehicle, VSRD-MAP 2249-8303 Volume2 (1), 9-16, 2012

[6]. Mr. V. Lakshmi Narayana, “Design and Analysis Of Mono Composite Leaf Spring For Suspension in Automobiles” IJERT 2278-0181, Vol. 1 Issue 6, August – 2012

[7]. Shishay Amare Gebremeskel, “Design, Simulation, and Prototyping of Single Composite Leaf Spring for Light Weight Vehicle”, Global Journals Inc. (USA) 2249-4596, Volume 12 Issue 7, 21-30, 2012

[8]. Manas Patnaik, NarendraYadav, “Study of a Parabolic Leaf Spring by Finite Element Method & Design of Experiments” , IJMER 2249- 6645, Vol.2, 1920-1922, July-Aug 2012

[9]. Kumar Krishan, Aggarwal M.L, “Computer Aided FEA Comparison of mono steel and mono GRP leaf spring”, IJAERS 2249–8974, vol. 1 issue 2, pp. 155-158, jan- march 2012.