ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 2, Issue 2, February 2016

Design and Analysis of Composite Leaf Spring for Suspension in Heavy Automobiles

[1]P.Guruanandamurugan, [2]M.Manoj, [3]A.Jafer Sathick, [4]T.Rebin.
[1234]PSN College of Engineering & Technology, Tirunelveli, TN, India
Email: anandamurugan17@gmail.com

***Abstract*— The Automobile Industry has shown increase interest for replacement of steel leaf spring with that of composite leaf spring, since the composite material has high strength to weight ratio, good corrosion resistance. The paper describes static and dynamic analysis of steel leaf spring and laminated composite Multi leaf spring. The objective is to compare displacement, frequencies, deflections and weight savings of composite leaf spring with that of steel leaf spring. The dimensions of an existing conventional steel leaf spring of a Light design calculations. Static and Dynamic Analysis of 3-D model of conventional leaf spring is performed using ANSYS 10.0. Same dimensions are used in composite multi leaf spring using S2 Glass/Epoxy and Kevlar/Epoxy unidirectional laminates. Analysis is done by layer stacking method for composites by changing reinforcement angles for 3 layers, 5 layers and 11 layers. The weight of composite leaf spring is compared with that of steel leaf spring. The design constraints are stresses and deflection. A weight reduction of 27.5 % is achieved by using composite leaf spring.**

***Index Terms*—Mild Steel, Kevlar/Epoxy, S2 Glass/Epoxy, Leaf Spring, Static Analysis, Dynamic Analysis FEA.**

I. INTRODUCTION

Suspension can be considered as a link between the wheels and the body. It absorbs quick loadings and collects the elastic energy. Design fundamentals are based on the strength and comfort. The strength characteristics are usually determined according to the suspension type and loading. The comfort design fundamentals originate from the fluctuation and vibration point of view. The basic idea for the design is to generate the wanted elasticity and maintain the driving comfort. Suspensions mechanisms also can use different types of springs in the mechanism. The most common are the coil spring, torsion bar, pneumatic, and leaf spring. The choice of spring normally has little effect on suspension performance.

A. Leaf Springs

Leaf springs were the suspension of choice in the early days of the automobile. They have the advantage of using the same mechanism to control the wheel and provide the necessary spring force. They are simple, inexpensive, and easy to manufacture. Nowadays it is widely used in heavy duty vehicles and work machines.

The advantages of the leaf spring are based on its simple construction, low costs and easy maintenance. The design also provides the solution for the axle support. Almost all vehicle suspension uses parabolic leaf springs. The difference between the normal leaf spring and the parabolic leaf spring is the total number of leafs. A parabolic leaf does not need of huge amount of leafs because the stress is distributed equally due to its parabolic shape.

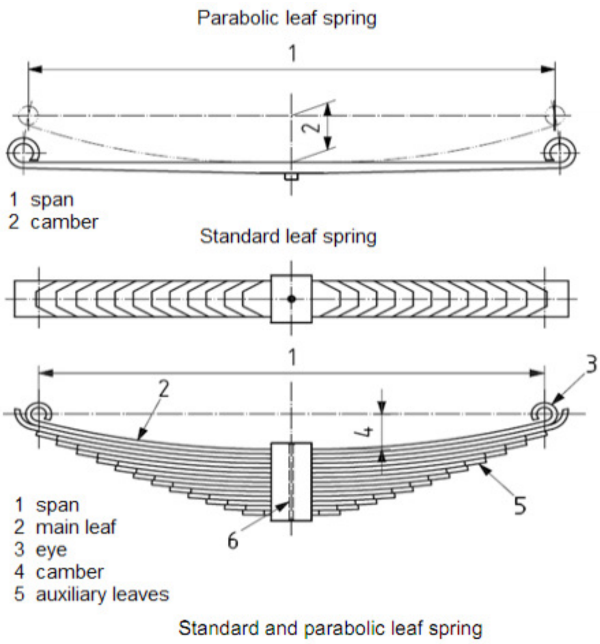


Fig. 1: Parabolic of Leaf Spring

B. Advantages and Disadvantages of Leaf Spring

In terms of function, leaf spring suspensions are much simpler, since the axle is suspended by the spring, and does not require the complicated suspension geometry of the coil-spring set-up. Leaf springs are also much sturdier, and are capable of handling much higher loads with less deflection than coils. Trucks with leaf springs are also easier to raise or lower.

The leaf springs simplicity is as much a curse as a blessing. Since these springs attach at fixed points on the chassis, they give very little room for adjustability of suspension geometry. These springs also flex a great deal less than coil springs, resulting in a loss of wheel-to-ground contact under extreme conditions.

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 2, Issue 2, February 2016

C. Objective of the Work

In the present scenario, weight reduction has been the main focus of automobile manufactures. The suspension leaf spring is one of the potential items for weight reduction in automobiles as it accounts for ten to twenty percent of the unstrung weight, which is considered to be the mass not supported by the leaf spring. The introduction of composite materials made it possible to reduce the weight of the leaf spring without any reduction on the load carrying capacity and stiffness. Studies were conducted on the application of composite structures for automobile for automobile suspension system.

The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. According to the studies, a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring.

In the present work, a nine-leaf steel spring used in heavy vehicle is replaced with a composite multi leaf spring made of S2 Glass/Epoxy and Kevlar/Epoxy. The dimensions and the number of leaves for both steel leaf spring and composite leaf springs are considered to be the same. The objective is to compare their displacement, frequencies, deflections and weight savings of composite leaf spring.

II. LITERATURE REVIEW

Investigation of composite leaf spring in the early 60's failed to yield the production facility because of inconsistent fatigue performance and absence of strong need for mass reduction. Researches in the area of automobile components have been receiving considerable attention now. Particularly the automobile manufacturers and parts makers have been attempting to reduce the weight of the vehicles in recent years. Emphasis of vehicles weight reduction justified taking a new look at composite springs. Studies are made to demonstrate viability and potential of composite materials in automotive structural application.

Recent developments have been achieved in the field of materials improvement and quality assured for composite leaf springs based on microstructure mechanism. All these literature report that the cost of composite; leaf spring is higher than that of steel leaf spring.

Hence an attempt has been made to fabricate the composite leaf spring with the same cost as that of steel leaf spring.

Material properties and design of composite structures are reported in many literatures. Very little information is available in connection with finite element analysis of leaf spring in the literature, than too in 2D analysis of leaf spring. At the same time, the literature available regarding experimental stress analyses are more.

III. DESIGN OF LEAF SPRING

A spring is defined as an elastic machine element, which deflects under the action of the load and returns to its original shape when the load is removed. It can take any shape and form depending upon the application. The important functions and applications of springs are as follows:

Springs are used to absorb shocks and vibrations, e.g., vehicle suspension springs, railway buffer springs, buffer springs in elevators and vibration mounts for machinery.

- Springs are used to store energy, e.g., springs used in clocks, toys, movie-cameras, circuit breakers and starters.
- Springs are used to measure force, e.g., springs used in weighing balances and scales.
- Springs are used to apply force and control motion.

There are a number of springs used for this purpose. In the cam and follower mechanism, spring is used to maintain contact between the two elements. In engine valve mechanism, spring is used to return the rocker arm to its normal position when the disturbing force is removed. The spring used in clutch provides the required force to engage the clutch. In all these applications, the spring is used either to apply the force or to control the motion.

The leaf spring has a bending stress which must be equally distributed along the structure. In mathematical point of view, the leaf spring can be considered as a cantilever beam. The bending stress in the arbitrary distance x can be expressed with the equation.

$$\delta_{tx} = \frac{M_t}{W} = Const$$

Where M_t is bending moment and W is bending resistance. This equation qualifies for a spring which has regular cross-section area. Bending stress σ_t for the parabolic leaf spring can be expressed with the equation

$$\delta_t = \frac{M_x h_x}{I_x^2}$$

Where M_x is the bending moment, h_x is the thickness of the leaf and I_x is the second moment of area. I_x and h_x are usually expressed as functions in the parabolic leaf. The vehicle suspension is shown in fig. It has the solid axle and wheels are mounted to a frame with two leaf springs.

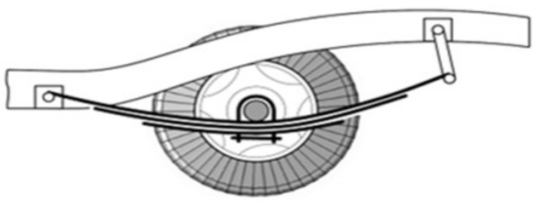


Fig. 3: Leaf Spring Mounting on the Chassis

The drive is the simplest solution for suspension and linkage between the frame and axle. The solution has problematic dynamics which are due to low mass ratio. The

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 2, Issue 2, February 2016

mass ratio means relation between the supported and unsupported mass and it can be expressed with the equation

$$\varepsilon_m = \frac{m_u}{m_s}$$

Where ms is the mass of bodies, which are supported by a spring, like the vehicle's body, mu is the mass of those bodies that are mounted to a spring but not supported, like axle and tires. In this construction, springs are acting as a locating member. Demanded property of the spring is to flex under loading to the one direction. In this drive the leaf spring goes under lateral and longitudinal loading.

This usually leads to a situation where the spring is bended to also called S curve, when braking and accelerating. Braking and accelerating situations are shown in figure. Inertial forces of the frame and body are also creating longitudinal twisting torque to the spring.

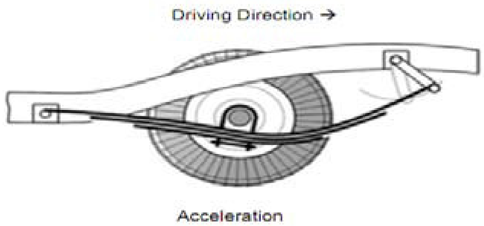


Fig. 4: Position of the Leaf Spring during Acceleration

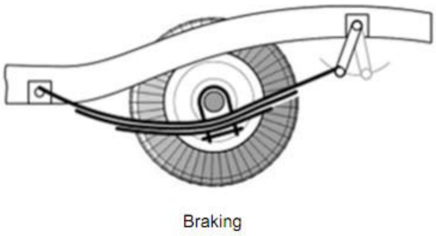


Fig. 5: Position of the Leaf Spring during Braking Modeling and Analysis

A. *Modeling of Leaf Spring*

Pro/ENGINEER is a feature based, parametric solid modeling system with many extended design and manufacturing applications which is developed by PARAMETRIC TECHNOLOGY CORPORATION, as a comprehensive CAD/CAE/CAM system, covering many aspects of mechanical design, analysis and manufacturing, Pro/ENGINEER represent the leading CAD/ CAM/CAE technology.

The solid model of the laminated leaf spring component part can be created through the following steps

Create the parts of the laminated leaf spring with a coordinate system. Datum Planes are chosen as reference planes for constructing and dimensioning solid models. Commands like, sketch, extrude, line, circle, arc are used for creating the leafs for the spring. Since Pro engineer is feature based design software, it is very simple to create solid parts in it Assemble the created parts. Proper constraints like, mate, align, move, rotate, spin etc., are given while assembling the parts to form the final component for the analysis. The final component is converted into an iges file to export into ANSYS for analysis. The iges file is created as solid part.

Figure shows the main leaf spring created in Pro Engineer software. It has two eye ends for arresting the leaf spring.

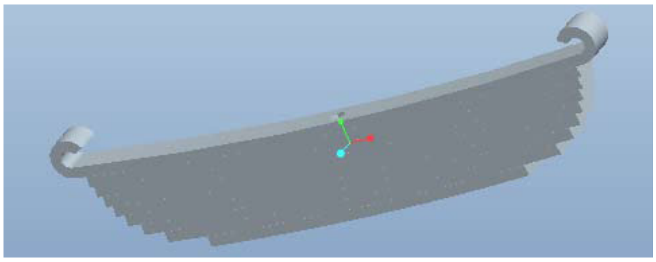


Fig. 6: Main Leaf of the Laminated Leaf Spring

B. *Model Generation*

In ANSYS terminology, model generation usually takes on the narrower meaning of generating the nodes and elements that represent the spatial volume and connectivity of the actual system. Thus, model generation in this discussion means the process of defining the geometric configurations of the model's nodes and elements. The ANSYS program offers the following approaches of model generation.

Creating a solid model within ANSYS using direct generation of the component within the software itself or importing model created in any other computer aided design software which is compatible with Ansys software. Direct generation of solid in Ansys software is somewhat tedious because the person who knows completely about Ansys software can create few parts in software. Some parts with complicated structure and dimensions cannot be created by this software. In these cases, it is better to model the problem in any other computer aided design software and import the component for analysis into this Ansys software, because created a complete component in Ansys software is somewhat time consuming processes.

C. *Importing the model.*

As an alternative to creating the solid models within ANSYS, we can create them in favorite CAD system and then import them into ANSYS for analysis, by saving them in the IGES file format or in a file format supported by an ANSYS connection product. Creating a model using a cad package has the following advantages:

We avoid a duplication of effort by using existing cad models to generate solid models for analysis. We use more familiar tools to create models. However, models imported from cad systems may require extensive repair if they are not of suitable quality for meshing.

While building the Model in the CAD systems we to observe Ansys solid modeling procedures with regard to planning, symmetry and the amount of detail needed for a finite element analysis. For example, for axis symmetric models, the Ansys program requires that the global Y axis be

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

IJARMATE
Your ulti-MATE Research Paper !!!

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 2, Issue 2, February 2016

the axis of rotation. Avoid creating closed curves (that is, a line that starts and ends at the same point) and closed surfaces (such s a surface that starts and ends at the same edge). Ansys can't store closed curves or closed surfaces (it requires at least two key points). If a closed curve, closed surface, or "trimmed" closed surface defined by IGES entities, Ansys will attempt to split it into two or more entities as much as possible, write to the iges file by data that the Ansys program supports.

D. Analysis of the leaf spring.

Structural analysis is the most common application of the finite element engineering structures such as bridges and buildings, but also naval, aeronautical, and mechanical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools.

The seven types of structural analyses available in the ANSYS family of products are explained below. The primary unknowns (nodal degrees of freedom) calculated in a structural analysis are displacements. Other quantities, such as strains, stresses, and reaction forces, are then derived from the nodal displacements. Structural analyses are available in the ANSYS Multi physics, ANSYS Mechanical, ANSYS Structural, and ANSYS Professional programs only.
You can perform the following types of structural analyses. Each of these analysis types are discussed in detail in this manual.

1. Static Analysis
Used to determine displacements, stresses, etc. under static loading conditions both linear and nonlinear static analyses. Nonlinearities can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces, and creep.

2. Modal Analysis
Used to calculate the natural frequencies and mode shapes of a structure. Different mode extraction methods are available.

3. Harmonic Analysis
Used to determine the response of a structure to harmonically time-varying loads.

4. Transient Dynamic Analysis
Used to determine the response of a structure to arbitrarily time varying loads. All nonlinearities mentioned under Static Analysis above are allowed.

5. Spectrum Analysis
An extension of the modal analysis, used to calculate stresses and strains due to a response spectrum or a PSD input (random vibrations).

6. Buckling Analysis
Used to calculate the buckling loads and determine the buckling mode shape. Both linear (Eigen value) buckling and nonlinear buckling analyses are possible.

7. Explicit Dynamic Analysis
This type of structural analysis is only available in the ANSYS LS-DYNA program. ANSYS LS-DYNA provides an interface to the LS-DYNA explicit finite element program. Explicit dynamic analysis is used to calculate fast solutions for large deformation dynamics and complex contact problems.

In addition to the above analysis types, several special-purpose features are available:

- Fracture mechanics
- Composites
- Fatigue
- P-Method
- Beam Analyses

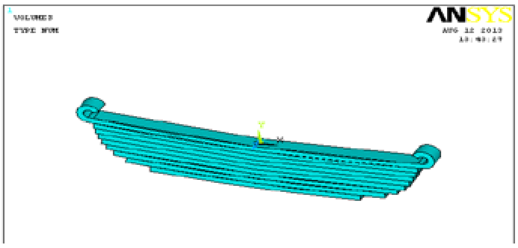


Fig 7: Solid 20 Node 95 Element Type Used For Analysis

E. Element Type

Symmetry is considered and only one half is taken into consideration for analysis. The middle portion is arrested and the load is applied at the end of the leaf spring. Solid 45 8-noded elements are chosen for analysis. Solid 45 is used for the 3-D modeling of solid structures.

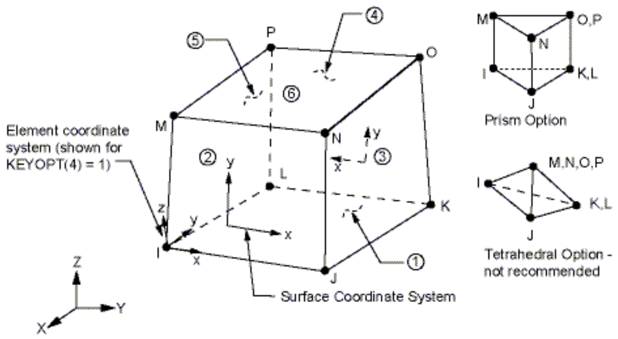
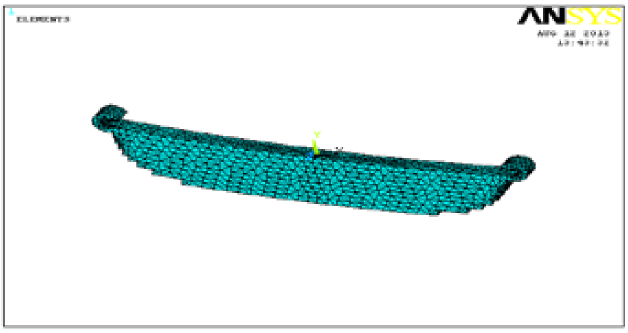


Fig. 8: Solid 45 Element Type Used for Analysis

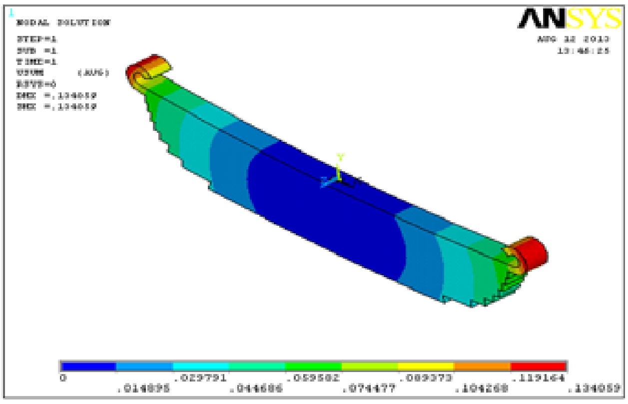
Meshing of Leaf Spring

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

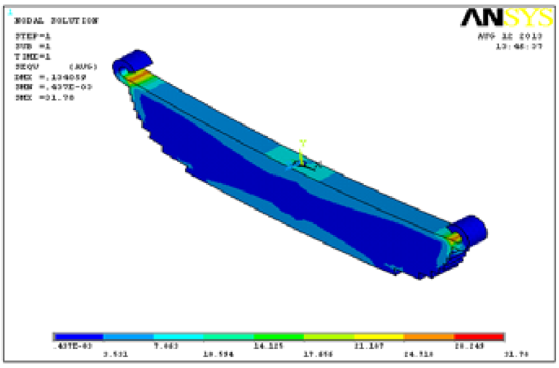
International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 2, Issue 2, February 2016



Displacement vector sum:

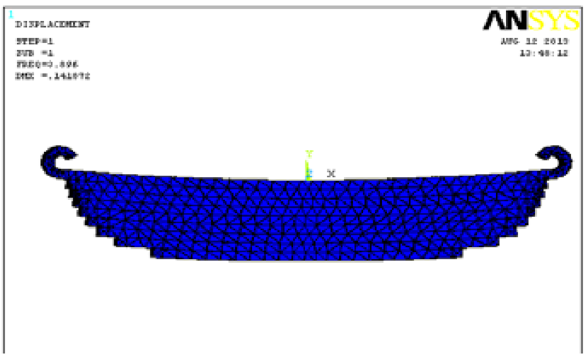


Von mises stress:

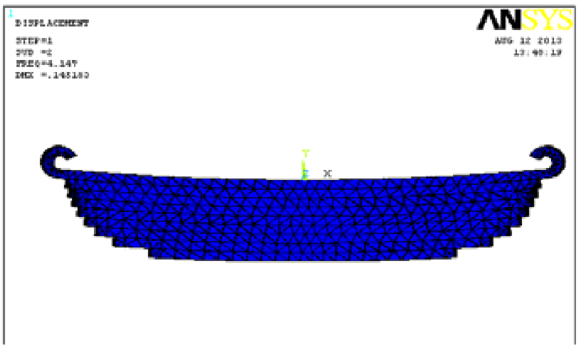


Modal analysis:

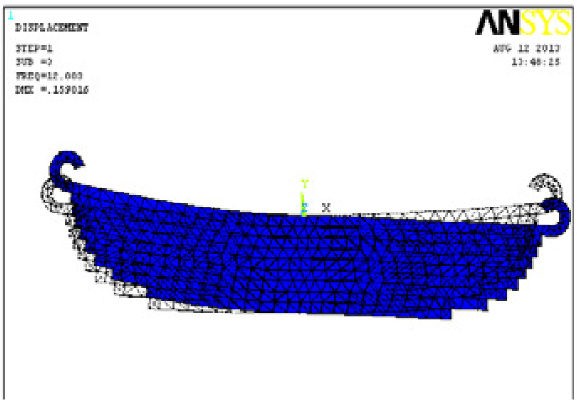
Mode-1:



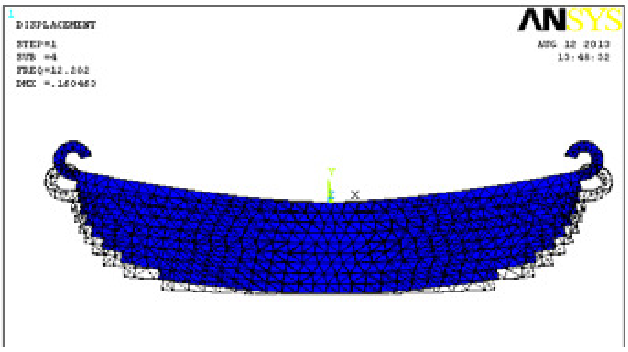
Mode-2:



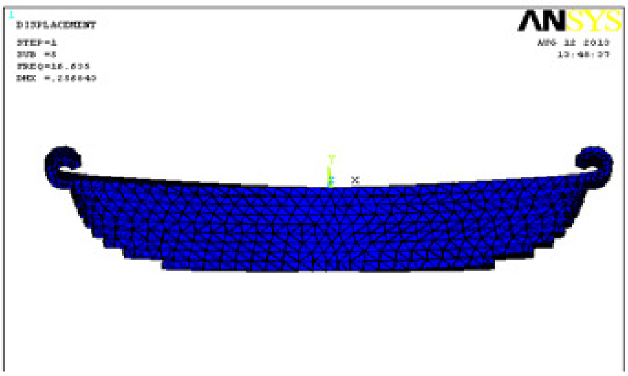
Mode-3:



Mode-4:



Mode-5:



ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

IJARMATE
International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 2, Issue 2, February 2016

Layer method:
3-Layres:

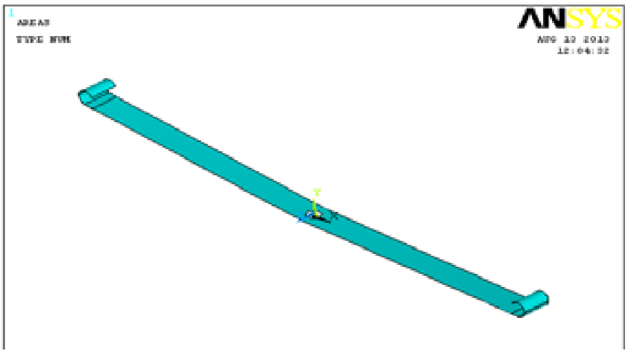
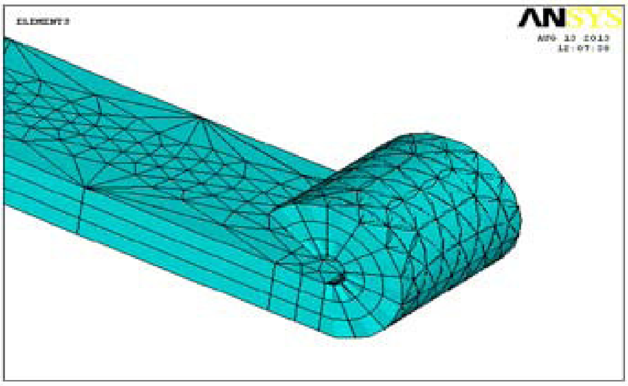
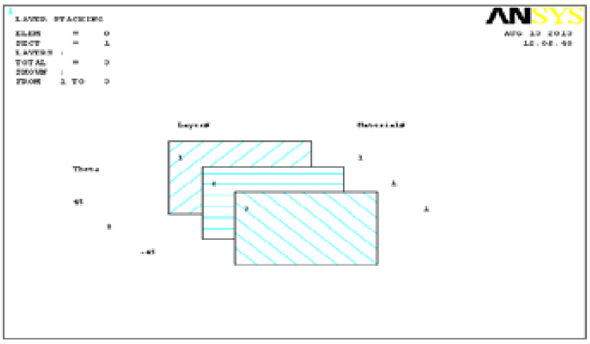


Fig. 9: Layer 20 Node 95 Element Type Used For Analysis

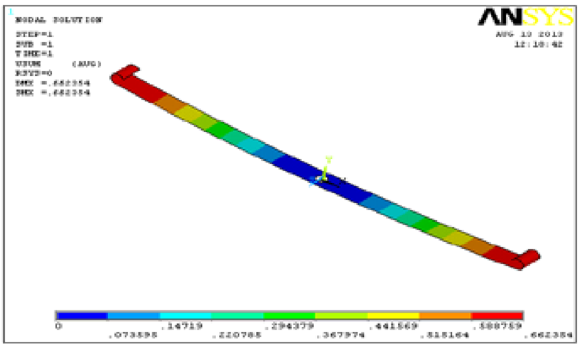
Meshing of leaf spring:



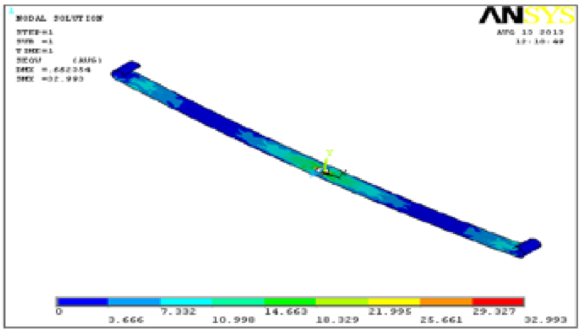
Layer method:



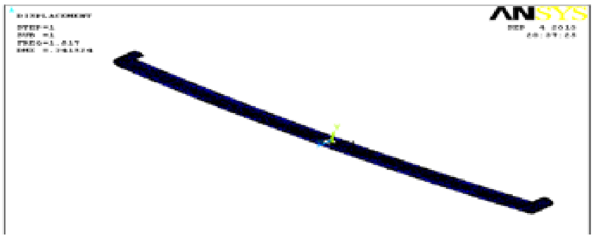
Displacement Vector Sum:



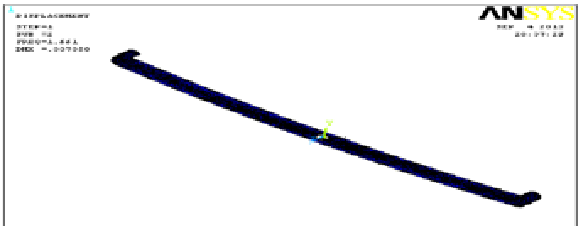
Von Mises Stress:



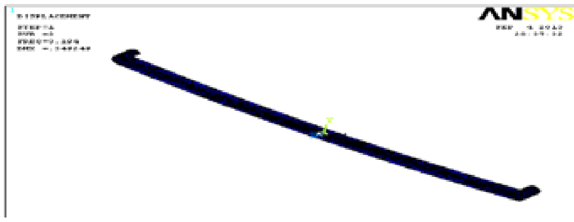
Modal analysis:
Mode-l:



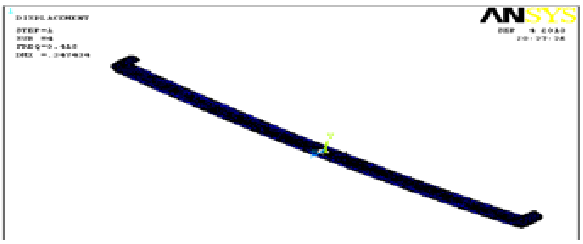
Mode-2:



Mode-3:



Mode-4:

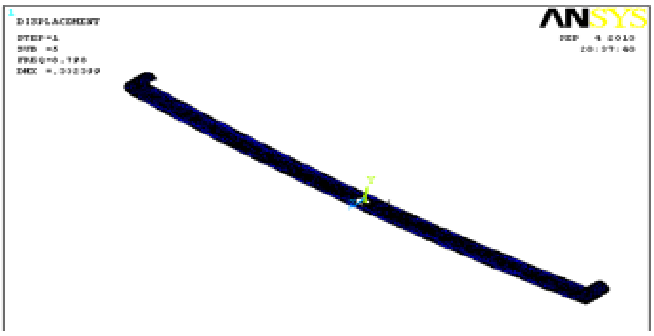


ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

IJARMATE
Your ult-MATE Research Paper !!!

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 2, Issue 2, February 2016

Mode-5:



IV. Result And Discussions

Observing the graphs of Displacement, Stress, Frequencies and Deflection valves are as follows. By using composites, the displacement values are higher than Mild Steel.

By observing the modal analysis results, the vibrations produced are less for composites than mild steel since their frequencies are less. When comparing 3, 5 and 11 layers using 5 layers is better, since the frequencies are less.

By comparing the results for 3 materials, using Epoxy Matrix Composite reinforced by 50% Kevlar fibers is better since it's weight is less and also stresses values and frequencies analyzed are less than S2 Glass.

Table 1: Structural Method

		Mild Steel	Kevlar	S2 Glass
Structural	Displacement (mm)	0.134059	25.655	7.92
	Stress (N/mm2)	3.78	261.489	262.08
Mode-1	Deflection (mm)	0.141872	0.58409	0.440237
	Frequency (Hz)	3.896	3.147	4.314
Mode-2	Deflection (mm)	0.145183	0.59943	0.450121
	Frequency (Hz)	4.147	3.313	4.513
Mode-3	Deflection (mm)	0.159016	1.05	0.782974
	Frequency (Hz)	12.003	4.579	6.215
Mode-4	Deflection (mm)	0.160463	1.054	0.786165
	Frequency (Hz)	12.202	4.601	6.241
Mode-5	Deflection (mm)	0.256843	0.893939	0.65943
	Frequency (Hz)	16.635	9.452	12.864

Table 2: 3 Layer methods

		Mild Steel	Kevlar	S2 Glass
Structural	Displacement (mm)	0.662354	44.724	13.428
	Stress (N/mm2)	32.993	77.207	78.312
Mode-1	Deflection (mm)	0.341524	0.949859	0.720300
	Frequency (Hz)	1.617	0.600993	0.822107
Mode-2	Deflection (mm)	0.337358	0.946333	0.71772
	Frequency (Hz)	1.661	0.605589	0.827778
Mode-3	Deflection (mm)	0.349249	0.7802	0.592167
	Frequency (Hz)	3.194	1.707	2.359
Mode-4	Deflection (mm)	0.347434	0.788359	0.597546
	Frequency (Hz)	3.415	1.791	2.46
Mode-5	Deflection (mm)	0.332399	0.916189	0.693036
	Frequency (Hz)	8.798	3.254	4.453

Table 3: 5 Layer Methods

		Mild Steel	Kevlar	S2 Glass
Structural	Displacement (mm)	0.657708	44.653	13.408
	Stress (N/mm2)	27.73	77.259	78.365
Mode-1	Deflection (mm)	0.001795	0.949455	0.720105
	Frequency (Hz)	0.00849	0.601222	0.822404
Mode-2	Deflection (mm)	0.001787	0.94596	0.717542
	Frequency (Hz)	0.008562	0.605784	0.828029
Mode-3	Deflection (mm)	0.001473	0.78022	0.592194
	Frequency (Hz)	0.016214	1.707	2.36
Mode-4	Deflection (mm)	0.001487	0.788371	0.597566
	Frequency (Hz)	0.017089	1.791	2.461
Mode-5	Deflection (mm)	0.001759	0.916133	0.693034
	Frequency (Hz)	0.046199	3.255	4.455

Table 4: 7 Layer Methods

		Mild Steel	Kevlar	S2 Glass
Structural	Displacement (mm)	0.66207	42.274	12.672
	Stress (N/mm^2)	32.987	59.78	61.012
Mode-1	Deflection (mm)	0.341297	0.701174	0.531056
	Frequency (Hz)	1.618	0.606438	0.830049
Mode-2	Deflection (mm)	0.33718	0.705668	0.5343
	Frequency (Hz)	1.662	0.626675	0.858495
Mode-3	Deflection (mm)	0.348985	0.90094	0.70223
	Frequency (Hz)	3.196	1.734	2.398
Mode-4	Deflection (mm)	0.347178	0.90394	0.703386
	Frequency (Hz)	3.417	1.805	2.482
Mode-5	Deflection (mm)	0.332376	0.678419	0.51623
	Frequency (Hz)	8.803	3.304	4.525

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 2, Issue 2, February 2016

V. CONCLUSIONS

The following conclusions can be drawn from the present work:-

1. By replacing the material with composites, the weight of the leaf spring is reduced, the weight is reduced almost by 267kgs when Kevlar is used and almost by 246kgs when S2 Glass is used. The strength of the composites is more when compared to that of Mild Steel.
2. Analysis is done by layer stacking method for composites by changing reinforcement angles for 3 layers, 5 layers and 11layers. The stress values are safe. But by using composites, the displacement values are higher than Mild Steel.
3. By observing the modal analysis results, the vibrations produced are less for composites than mild steel since their frequencies are less. When comparing 3, 5 and 11 layers using 5 layers is better. Since the frequencies are less.
4. By comparing the results for 3 materials, using Epoxy Matrix Composite reinforced by 50% Kevlar fibers is better since its weight is less and also stresses values and frequencies analyzed are less than S2 Glass.

REFERENCES

[1] Hawang, W., Han, K. S.,"Fatigue of Composites – Fatigue Modulus Concept and Life Prediction", Journal of Composite Materials, 1986.
[2] Dharam, C. K.,"Composite Materials Design and Processes for Automotive Applications", The ASME Winter Annual Meeting, San Francisco, 1978.
[3] AL-Qureshi, H. A.,"Automobile leaf springs from composite materials", Journal of Processing Technol., 2001.
[4] Springer, George S., Kollar, Laszloa P.,"Mechanics of Composite Structures", Cambridge University Press, New York, 2003. [5] R.S. Khurmi, J.K. Kupta,"A text book of Machine Design", 2000.
[6] Daugherty, R. L.,"Composite Leaf Springs in Heavy Truck Applications", K. Kawata, T.Akasaka (Eds). Composite Materials Proceedings of Japan-US Conference Tokyo,1981
[7] H.A. AL-Qureshi,"Automobile Leaf springs from composite materials", Journal of Material Processing Technology, 118, 2001, pp. 58-61.
[8] Peiyong Qin, Glenn Dental, Mikhail Mesh,"Multi-Leaf Spring and Hotchkiss Suspension", ABAQUS Users' Conference, 2002.
[9] A.M. Wahl,"Mechanical Springs", Mc Graw-Hill, 1984.
[10] Masayoshi Simozeki,"FEM on springs", Japan Society of Spring Engineers, 1997
[11] ANSYS User Manual V10.0, Ansys Inc.
[12] "Materials Science and Engineering", John Willey and Sons Inc, 2003.
[13] Malick P. K,"Fiber reinforced composite materials (manufacturing & design)", second edition, Marcel-Dekker, 1998.
[14] [Online] Available: http://www.matweb.com
[15] [Online] Available: http://www.nhtsa.com
[16] [Online] Available: http://www.azom.com

AUTHORS BIOGRAPHY

GURUANANDA MURUGAN P was born in 1995. He is currently a UG Scholar in PSN college of Engineering and Technology Tirunelveli, in the Department of Mechanical Engineering. His research interests includes production and manufacturing Engineering.

MANOJ M was born in 1994. He is currently a UG Scholar in PSN college of Engineering and Technology Tirunelveli, in the Department of Mechanical Engineering. His research interests include Automobile Related Ideas and Production Engineering.

JAFAR SATHICK A was born in 1992. He is currently a UG Scholar in PSN college of Engineering and Technology Tirunelveli, in the Department of Mechanical Engineering. His research interests include Automobile Related Ideas and Manufacturing Design.

REBIN.T was born in 1995. He is currently a UG Scholar in PSN college of Engineering and Technology Tirunelveli, in the Department of Mechanical Engineering. His research interests include Automobile Related Ideas and Production Engineering.