COMPUTERIZE DESIGN OF MONO LEAF SPRING USING COMPOSITE MATERIAL

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***Abstract*: In heavy vehicles leaf spring is used to restrict the impact shock and dump the vibration, generally they are made from steel which are very heavy. Composite materials (or composites for short) are materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure. So to reduce the weight of leaf spring here in this work it analyzed the effect of different light weight composite material to manufacture leaf spring. In this work it considered three different composite materials that is E-glass epoxy, graphite-epoxy and carbon-epoxy composite and calculate the value of alternating equivalent stress and total deformation for each material. Finite element analysis of leaf spring was performed using Ansys, and also find out the life cycles for each material by performing fatigue analysis. It is found that E-glass epoxy composite has the highest life cycle and less deformation as compared to other materials.**

***Keywords*: Leaf spring, Fatigue analysis, Composite materials, life cycle, Deformation**

1. Introduction

A leaf spring is a simple form of spring commonly used for the suspension in wheeled vehicles. Originally called a laminated or carriage spring and sometimes referred to as a semi elliptical spring or cart spring, it is one of the oldest forms of springing, appearing on carriages in England after 1750 and from there migrating to France and Germany. A leaf spring takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. In the most common configuration, the center of the arc provides location for the axle, while loops formed at either end provide for attaching to the vehicle chassis. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves. Leaf springs can serve locating and to some extent damping as well as springing functions. While the interleaf friction provides a damping action, it is not well controlled and results in restriction in the motion of the suspension. For this reason, some manufacturers have used mono-leaf springs. A leaf spring can either be attached directly to the frame at both ends or attached 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 of the 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. For heavy vehicles, they have the advantage of spreading the load more widely over the vehicle's chassis, whereas coil springs transfer it to a single point. Unlike coil springs, leaf springs also locate the rear axle, eliminating the need for trailing arms and a Pan hard rod, thereby saving cost and weight in a simple live axle rear suspension.

Composite materials (or composites for short) are engineered materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure. It is any substance employed in making some useful thing or artifact. The metals and ceramics are materials used in industries as good conductors and refractory materials respectively. Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material. Qian et.al (2017) in this analysis the study of composite leaf springs has been popular in automotive light weighting. Particularly, the research on the fatigue reliability of composite leaf springs is crucial. Noorman et.al (2014) in the present work laminated composite was review. Laminated composites are a material that is rapidly being adapted in the aircraft industry and new joining techniques are being researched for new structural designs. Reis et.al (2009) this paper is about representing the results of current research on the fatigue life prediction of carbon/epoxy laminate composites involving twelve balanced woven bidirectional layers of carbon fibers and epoxy resin manufactured by a vacuum molding method. Almeida et.al (2009**)** in this analysis a technique for the design optimization of composite laminated structures is presented. The optimization process is performed using a genetic algorithm (GA), associated with the finite element method (FEM) for the structural analysis. Naik et.al (2008) in this paper, minimum weight design of composite laminates is presented using the failure mechanism based (FMB), maximum stress and Tsai–Wu failure criteria.

Leaf springs are used to damp the vibration in heavy duty vehicles, conventionally metals are mainly prefer for the manufacturing of leaf spring due to their high reliability and life cycle. In order to with stand at very high fluctuation loads and vibrations, there springs were made of much heavier which create huge inertia, which decreases the performance of vehicles. In order to make leaf spring lighter researchers have tried different types of polymer and sandwich structure, some of the researchers have tried the composite materials. Here in this work three different types of epoxy composite used for the construction of leaf spring, here it considered only three epoxy composite because E-glass fibers, Graphite and carbon are the materials with have maximum strength as compared to other materials available. So here in this work it uses E-glass-epoxy composite, Graphite-epoxy composite and

Carbon-epoxy composite. For calculating the life of different composite materials as leaf spring here in this work fatigue analysis of leaf spring is performed and calculate value of equivalent stress, total deformation and number of life cycle.

2. Development of Solid model

Here in this work, the solid model of leaf spring is developed on the basis of geometric parameters given in the base paper. The geometric parameters used for the construction of leaf spring are total length of the spring (Eye to Eye), thickness of leaf, Width of leaf spring, No. of full length leave (Master leaf) (composite material) and Maximum load given on spring are 1200 mm, 15 mm, 60 mm, 1 and 18.1 kN. The solid model of leaf spring is shown in the below fig.

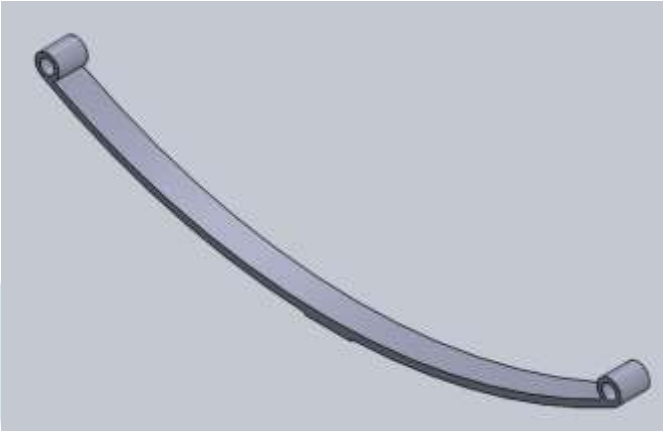

Fig.1 Solid model of leaf spring.

For analyzing the effect of different materials and performing the fatigue analysis, here it considered mono-leaf spring. After developing the solid model of leaf spring meshing were performed, during meshing in order to check the dependency of parameters on number of nodes and elements, here it perform the mesh with different numbers of nodes and elements. After doing mesh with different number of nodes it is find that the value of equivalent stress is not varying with respect to change in number of nodes.

2.1 Meshing

For performing the finite element analysis, it must be discretized in to number of node and element. For optimizing the mesh and checking the dependency of result on number of nodes and elements, here in this work it discretized leaf spring with different numbers of elements and nodes and evaluate the value of equivalent stress. When leaf spring discretized with 1508 number of elements value of equivalent stress is 450 MPa, whereas as it increases the number of elements for discretizing the body it varies and at 2601 number of elements it gives closer value of equivalent stress that is 482.48 MPa, which is the optimum value of number of elements for discretizing leaf spring. So in this analysis it discretizes the leaf spring with 2601 number of element having 16221 numbers of nodes.

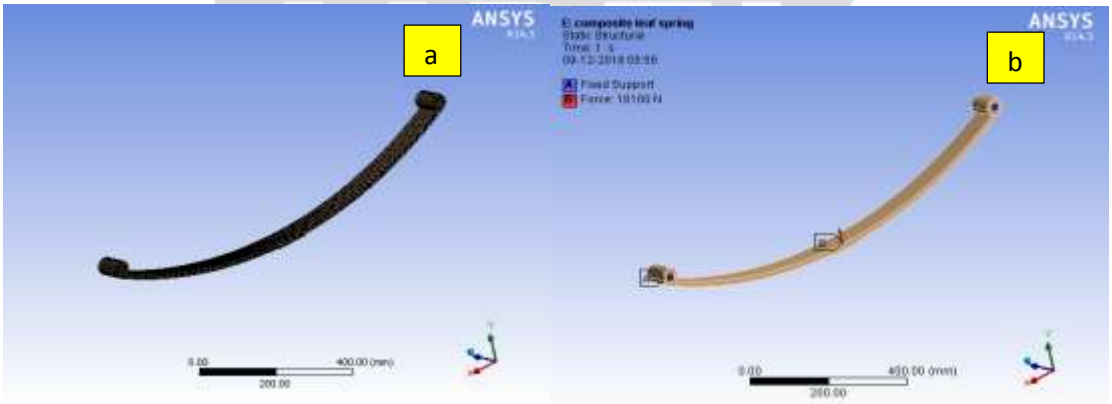

Fig.2 (a) Mesh of leaf spring having 2601 numbers of nodes and elements, (b) Application of load at the center of mono-leaf spring

2.2 Boundary conditions

After doing mesh of the solid model boundary conditions were applied on different parts of mono-leaf spring. Here in this analysis both eye of leaf spring were kept fixed and 18.1 kN load is applied at the center of the leaf spring. The application of load at the center of mono leaf spring is shown in the above fig.(b)

2.3 Material used

In order to make leaf spring lighter without compromising the life of spring, light weight composite materials were used for the manufacturing of leaf spring. Here in this work different light weight composite materials were used and fatigue analysis of each material were carried out to calculate number of life cycle till which the material can sustain without any facture. The properties of

different material used in this work is mention in the below section, here in this work it considered three different composite materials that is E-Glass epoxy, Graphite epoxy and carbon epoxy composite.

2.4 Fatigue life criteria and s-n curves:

For performing the fatigue analysis of leaf spring Hwang and Han developed an analytical fatigue model to predict the number of fatigue cycles to failure. The life data analysis is a tool to be used here to predict the fatigue life of mono composite leaf spring. The results are based on analytical result and resulting S-N graph [3]. The application of load during fatigue analysis was maintained in completely reverse cycle. The application of load during the fatigue analysis is shown in the below fig. and Goodman relation was considered for performing fatigue analysis which is mention in below fig. also.

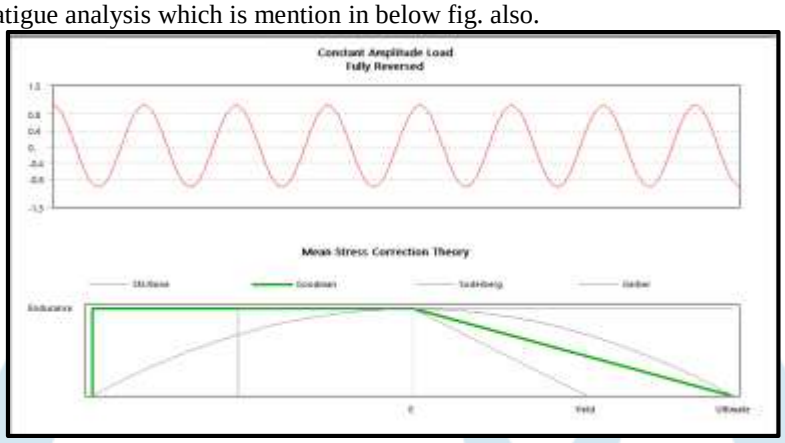

Fig.3 Criteria considered during the fatigue analysis.

For performing the fatigue analysis of different composite materials S-N curve of each composite material were imported in to software.

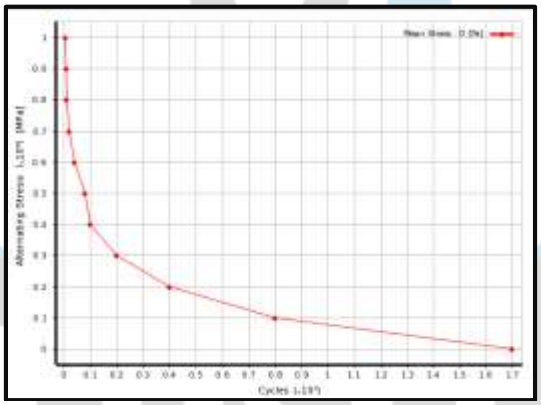

Fig.4 S-N curve of E-glass epoxy composite material.

3. Validation of FEM of leaf spring

For validating the Numerical analysis of leaf spring here it performs the numerical analysis of leaf spring on the basis of geometric and boundary conditions considered during experimental analysis performed by Qian et.al [1] and calculate the value of equivalent stress and compare it. After applying the different boundary condition on mono-leaf spring it calculates the value of equivalent stress. For the validation analysis here it considered E-glass epoxy composite and applied load as mention in the above section and calculate the value of maximum equivalent stress generate in leaf spring.

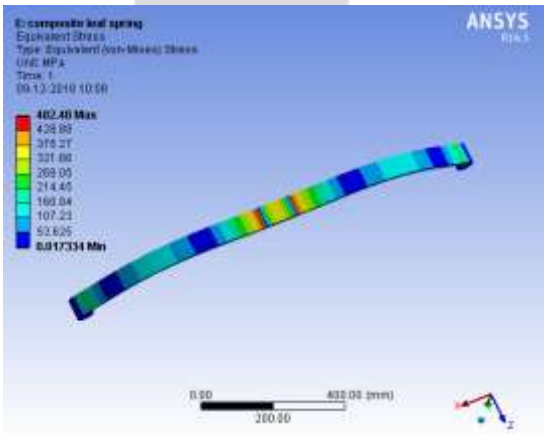

Fig.5 Contours of equivalent stress generated in mono-leaf spring.

Through above analysis it is founds that for E-glass epoxy the value of maximum equivalent stress is 482.48 MPa. Different colours in the above equivalent stress contours shows the value of different equivalent stress, maximum stress concentration region which is in red colour is at the center of the mono-leaf spring. The comparison of value of equivalent stress is shown in the below table.

Table.1 Comparison of different value of equivalent stress.

Equivalent Stress Calculated through FEM	Equivalent Stress Calculated by Qian et. al [1]	Error %
482.48 MPa	469.9 MPa	12.58

Through FEM analysis it is found that the value of equivalent stress is 483 MPa whereas the value of equivalent stress at the same load obtained from Qian et. al [1] is 470 MPa. The difference in between the experimental analysis and numerical analysis is much lower and it is under considerable. So the finite element analysis of leaf spring is correct. After validating the FEM model of leaf spring here in this work, it considered different light weight composite materials for the manufacturing of leaf spring and carry out the fatigue analysis. For performing the fatigue analysis on each material boundary condition where remain same that is load applied and other conditions remain same. Goodman criteria are considered for performing fatigue analysis during all materials analysis and calculate the value of life cycle for each material.

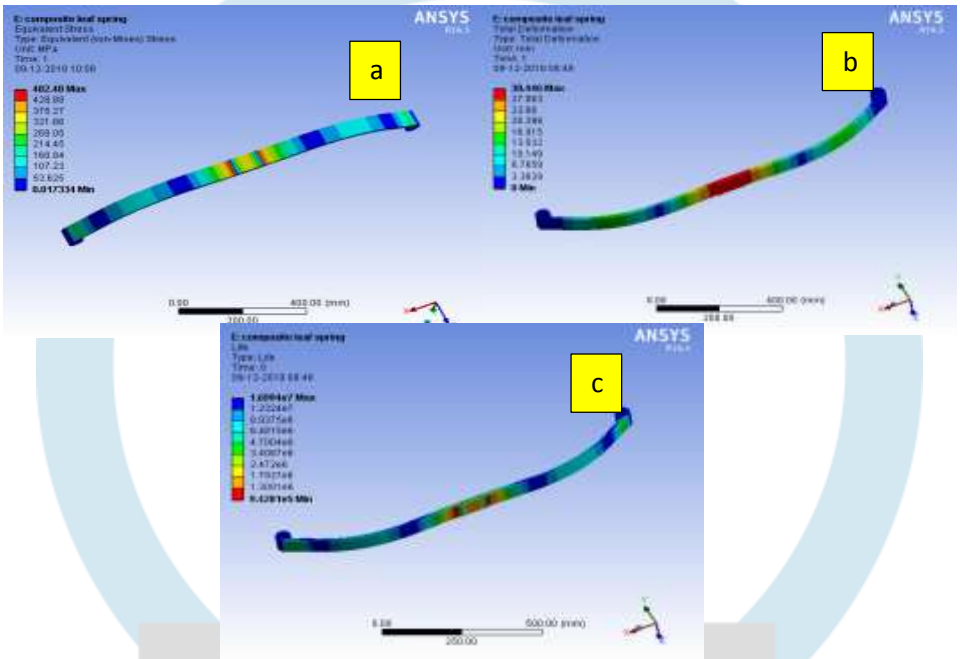

Fig. (a) Contours of equivalent stress for mono-leaf spring of E-glass epoxy composite, (b) Contours of total deformation along the mono-leaf spring for E-glass epoxy composite, (c) Contours of fatigue life cycles of mono-leaf spring

E-glass epoxy composite is considered for the manufacturing of leaf spring. The boundary conditions and other load applications were also remain same as considered in the above analysis. The value of alternating stress, total deformation and the value of number of life cycles obtained during fatigue analysis for E-glass epoxy composite is shown here. Through analysis it is found that for E-glass epoxy composite, the value of maximum deformation is 30.44 mm. whereas through deformation contours it is found that, maximum deformation is taking place at the middle of leaf spring at which stress concentration is also very high. The contours of fatigue life of E-glass composite leaf spring is shown in the below fig.

Through analysis it is founds that the value of equivalent alternating stress for E-glass epoxy is 428 Mpa, whereas the value of total deformation during analysis is 30.44 mm and fatigue life of leaf spring made from E-glass epoxy is near about 942810 Cycles. Through numerical analysis, fatigue sensitivity of material was also calculated. For E-glass epoxy material, the fatigue life sensitivity curve is shown in the below fig.

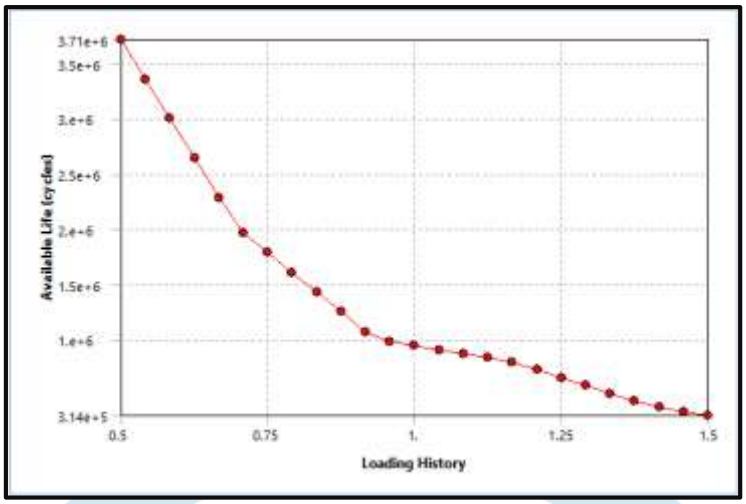

Fig. Fatigue sensitivity curve for E-glass epoxy composite.

4. Comparison of Different composite materials

For finding the best optimum lightweight composite materials for the construction of mono-leaf spring, it is necessary to compare different composite materials on the basis of different performance parameters. As considered lightweight materials during the analysis, lightweight materials are those materials whose density is less than 4.5 g/cc. the purpose of this work is to make leaf spring lighter in weight with enhance fatigue life. In conventional manufacturing mostly industries are using structure steel alloys for the manufacturing of leaf spring which is having very high density that is near about 7.8 g/cc. due to high density, weight of the complete leaf spring assembly becomes very heavy which increases the inertia of the vehicle which consumes extra energy during motion. Table showing the comparison of different material on the basis of different performance parameters were mention in below section.

Table.2 Comparison of different materials on the basis of different performance parameters.

S. No.	Material used for leaf spring (Composites)	Equivalent alternating(VON MISES) Stress (MPa)	Total deformation (mm)	Fatigue life cycle
1	E-Glass Epoxy	428	30.44	942810
2	Graphite Epoxy	745	36.75	760150
3	Carbon Epoxy	719.5	34.2	449230

Through above analysis it is found that E-glass epoxy composite shows the maximum number of cycle with low deformation and also with low equivalent alternating stress value as compared to graphite epoxy and carbon epoxy composite. With the help of above comparison it is concluded that graphite and carbon based epoxy composite shows very high equivalent stresses as compared to E-glass composite. Due to high stress generation in leaf spring, graphite and carbon based composite shows higher deformation values as compare to E-glass composite. With the increase equivalent stress generation during loading, fatigue life of graphite and carbon composite decreases compared to E-glass composite. Here it is concluded that E-glass epoxy composite is most suitable for the construction of lightweight composite leaf spring. Using different composites have advantage of less weight as compared to other to conventional leaf spring with makes composite leaf spring as lightweight materials. The density of different composites used for manufacturing of leaf spring is mention in below section.

Table.3 Density of different materials use for the construction of leaf spring.

S. No.	Material	Density
1	E-glass Epoxy	2700 kg/m^3
2	Graphite Epoxy	2160 kg/m^3
3	Carbon Epoxy	2000 kg/m^3
4	Structure Steel	7850 kg/m^3

The density of composite materials is much lower than the structural steel used for conventional leaf spring, as the volume of leaf spring is same for all materials, composite leaf springs are called as light weight structure.

5. Conclusion

In order to increase the life of the leaf spring and make it lighter, light weight composite material was used to manufacture leaf spring. Through analysis it is found that stress generated in E-glass epoxy composite is 42 % less as compared to stress generated in graphite epoxy and carbon epoxy composite at same applied load. Due to less stress generation the fatigue life of the leaf spring is high for E-glass epoxy which is 24% higher than as compared to graphite composite materials. Maximum deformation occur during fatigue analysis is also less that is 30 mm in case of E-glass epoxy composite which is 20 % less the graphite epoxy composite . After computing the fatigue analysis and analyzing the different parameters it concluded that E-glass epoxy composite material is the optimum material for the construction of light weight composite leaf spring.

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