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Design and Analysis of Composite Built Leaf Spring Systems For Heavy and Light Vehicle

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Abstract - *In the present article, three altered composite-based mono leaf springs were designed and analysed. It was inferred from the analyses that 0° unidirectional glass fibre system have not generated the intended spring rate accurately. Consequently, alternating configurations of glass and carbon hybrid systems were studied. It was deduced from the studies that material configuration of [0°6G/0°2C/0°22GS] was generated the intended spring rate.*

Three different composite-based mono leaf springs including indicated material configurations were fabricated within the present study. Manufactured prototypes were also tested by using leaf spring test rig for defining the behavior of the prototypes experimentally. The achieved results were compared with FEA and it has been observed that the results are in the range of agreement.

***Key Words*: Leaf spring, composite material, Suspension system, Materials**

1. INTRODUCTION

Suspension system of any vehicles contains leaf spring to absorb road shocks. The vehicles must have a good suspension system that can deliver a good ride and good human comfort.

It is observed that the failure of steel leaf springs is usually ruinous. According to investigation have been done for the leaf spring the material having maximum strength and minimum modulus of elasticity in longitudinal direction is the appropriate material. In order to reduce the accidents, for this type of failures conventional steel leaf spring can be replaced by gradually failing composite leaf springs. By this, the weight of the vehicle may also be reduced though maintaining the strength of the leaf spring.

Composite materials are variants of two materials that produce effects, so the combined properties produced by the combination are different from the properties of any of its components. In today's situation, we have done this tenaciously in order to obtain different product design, manufacturing and service advantages.

In this part of study leaf spring is representative of those products, for which automobile manufacturers are working to get An optimal composite material that meets current strength and weight reduction requirements to replace existing leaf springs. A suspension system of vehicle is also an area where these modernizations are carried out regularly. More efforts are taken in order to increase the comfort of user. Appropriate balance of ease riding qualities and economy in manufacturing of leaf spring becomes a noticeable necessity. To improve the suspension system, many modifications have taken place over the time. Leaf spring systems, which affect the weight of the vehicle in addition to ride comfort and the stability, are important parts of the vehicle. Therefore, composite materials, which have many superior properties over metals such as low density, high strength, corrosion resistance, high fatigue life, high wear resistance, are convenient materials for these types of applications; it may reduce the weight reduction in automobiles as it accounts for 10% - 20% of the unsprang weight. This achieves the vehicle with more fuel efficiency and improved riding qualities. Inventions of parabolic leaf spring, use of composite materials for these springs are some of these latest modifications in suspension systems. A spring is defined as an elastic body whose function is to deform when a force is applied, and return to its original shape when the load is removed. A spring is an elastic body that can be twisted, pulled or stretched by a certain force. When the force is released, they can return to their original shape. The leaf spring(also known as flat springs) is made of a flat plate. Compared with the coil spring, the leaf spring has the advantage that the end of the spring can be guided along a certain path when it is deflected, so as to act as a structural member in addition to the energy absorbing device. Thus the leaf springs may carry lateral loads, brake torque, driving torque etc., in addition to shocks.

1.1. Aims of Present Study

The objective of present study is to obtain optimum composite leaf spring structures and also to fabricate the composite leaf spring prototypes.

For this purpose, a relationship between material selection, composite structure design, material properties and mechanical behaviour of the leaf spring was obtained.

Composite-based mono leaf spring has been designed and finite element analysis has been performed under given loading conditions. Validation of finite element model has been presented by the comparison of experimental data and numerical results.

Thus, quasi-static analysis of the created leaf spring model has been investigated by the finite element program ANSYS15.

2. LEAF SPRING APPLICATIONS OF COMPOSITE MATERIALS

Composite material means that two or more different materials combined on a macroscopic scale to obtain serviceable third material which usually demonstrates the best properties of the constituents (Jones 1999). Therefore, many researches have been presented by many scholars to get the best material combination on composite-based leaf spring applications. This chapter details the previous works on the applications, designs, finite element modeling and analysis, and manufacturing of composite leaf springs.

Deshmukh and Jaju [1] Fibber reinforced polymer leaf spring was designed so as to perform the function of rear suspension which consists of steel lower arms and coil springs. The three-door Ford Escort model was chosen to obtain low spring rate. Constant cross section design was chosen as this type design was proper for the selected fabrication technique and fibers could be fully aligned along the spring without interrupting.
Thippeswamy et al. [2] Composite leaf springs can be designed as mono leaf or multi leaf. Mono leaf composite leaf springs are given preference to the multi leaf springs as they provide fabrication easiness and interleaf friction cannot play a role in damage.
Gebremeskel [3] many structural components of the vehicles are subjected to cyclic loading which significantly affects the life of the structure. So, it is important to indicate the number of cycles to fail.
Güneş, M. D. [4] several kinds of parameters should be considered in the leaf spring design. Flexural stiffness is one of them and should be increased from ends to centre of the spring as bending plays a crucial role in the middle of the spring due to the vertical loading conditions.

2.1. Design of leaf spring

To know about the working principle of a leaf spring, we can take example of diving board of a swimming pool. The diving board is a cantilever with a load, the diver having its free end. The diver starts a to and fro swing of the board at the free end and utilizes the spring action of the board for jumping. The diving board basically is a leaf spring.
The leaf springs are widely used in suspension system of railway carriages and automobiles. But the form in which it is normally seen is laminated leaf spring. Let us consider the simply supported leaf of Lozenge shape for which the maximum stress and maximum deflection are known. From the stress and deflection equations the thickness of the spring plate, h, can be obtained as

The σ_{max} is replaced by design stress σ_{des}. Similarly, δ maxis replaced by δ des. E is the material property and depends on the type of spring material chosen. L is the characteristic length of the spring. Therefore, once the design parameters, given on the left side of the above equation, are fixed the value of plate thickness, h can be calculated. [5-10]

Substitution of h in the stress equation above will yield the value of plate width b.
In the similar manner h and b can be calculated for leaf springs of different support conditions and beam types.

2.2. Laminated semi-elliptic spring

The top leaf is known as the master leaf. The eye is provided for attaching the spring with another machine member. The amount of bend that is given to the spring from the central line, passing through the eyes, is known as camber. The camber is provided so that even at the maximum load the deflected spring should not touch the machine member to which it is attached. The camber shown in the figure is known as positive camber. The central clamp is required to hold the leaves of the spring. However, the bolt holes required to engage the bolts to clamp the leaves weaken the spring to some extent. Rebound clips help to share the load from the master leaf to the graduated leaf.

3.MATERIALS FOR LEAF SPRING

Materials for leaf spring are not as good as that for the helical spring. Plain carbon steel, Chromium vanadium steel, Chromium- Nickel- Molybdenum steel, Silicon- manganese steel, are the typical materials that are used in the design of leaf springs [11-15].
Standard sizes of leaf spring.
Width (mm): 25-80 mm in steps of 5mm
Thickness (mm): 2-8 mm in steps of 1mm, 10-16 mm in steps of 2 mm
In order to carry heavy loads, more additional full-length blades are placed under the main blades to carry heavy loads. This change of the standard laminated leaf spring we learned above will not change the stress value, but the deflection equation needs some correction.
The master leaf of a laminated spring is hinged to the supports. The support forces induce, stresses due to longitudinal forces and stresses arising due to possible twist. Hence, the master leaf is more stressed compared to other the graduated leaves. Methods to reduce additional stresses could be,

1. Master leaf is made of stronger material than the other leaves.
2. Master leaf is made thinner than the other leaves. This will reduce the bending stress as evident from stress equation.
3. Another common practice is to increase the radius of curvature of the master leaf than the next leaf.

Table-1: The density and the engineering constants of the material

Parameter	**Value**
Material	Structural steel
Density	7850 kg/m^3
Young's Modulus	2e11

Poisson's ratio	0.3
Bulk modulus	1.6e11
Shear modulus	7.69e10
Tensile yield strength	2.5e8
Strength coefficient	9.2e8
Strength exponent	-.106
Ductility coefficient	.213
Compressive strength	2.5e8

3.1. Mesh and Elements

Ansysa15/CAE enables users to create suitable grids in their analysis through a comprehensive toolbox [16-21]. The Ansys 15/CAE mesh module has several unique functions, such as controlling the shape of the unit, meshing technology and mesh quality. In addition, the grid quality of Fig-1 can be verified and enhanced through the grid module tool in Ansys 15.

Figure-1: Mesh analysis

In this work, proper element type was selected firstly to create meshes on the composite leaf spring model. C3D8R (An 8-node linear brick, reduced integration, hourglass control) elements were selected firstly as the element type in reference to the proposals of Ansys 15 documentations and literature studies. Moreover, the analyses were also done using other element types. C3D8R is a three dimensional, 8-node, reduced integration, hourglass control element. These solid (continuum) elements are generally used in the modelling of solid composites as they can comprise different material properties. This characteristic provides an advantage especially in the hybrid composite modelling including various plies of different materials. The geometry, the node numbering, the node locations and the face numbering of this element are demonstrated in Figure.

The aforementioned element has only one integration point at the element centroid. Therefore, the hour glassing can make some difficulties at the point of obtaining accurate results. Hence, the load conditions and the boundary values should be distributed over the many nodes to avoid from the hourglass effect. This element also enables users to create isotropic, engineering constants, lamina, orthotropic or anisotropic material properties in the model. In addition, output requests such as stresses, strains, displacements, reaction forces, reaction moments, contact stresses, contact forces, energy and damage components are available for this element type. Many problems can be meshed with global seeds in Ansys 15/CAE yet local seeds should be utilized in our model to obtain proper mesh generation and mesh density. Using linear reduced integration elements may cause some problems especially in bending problems as mentioned before though these elements provide advantages in terms of time consuming. Structures having bending loads should be studied carefully and minimum four elements should be used in the thickness direction of the structure

4. RESULTS

Fig shows the maximum deflection at middle of the leaf spring and it is gradually decrease toward fixed end or eye. Red colour shows in the figure high deflection zone the variation in the deflection shown by graph in fig 2. Fig 3 shows the equivalent stress which shows just nearer to the fixed hole where bolt used fig 3 is shows the variation of stress through the full span of the leaf spring similarly strain behavior in the leaf spring is also same the contour diagram and graph of equivalent strain shown in diagrams.

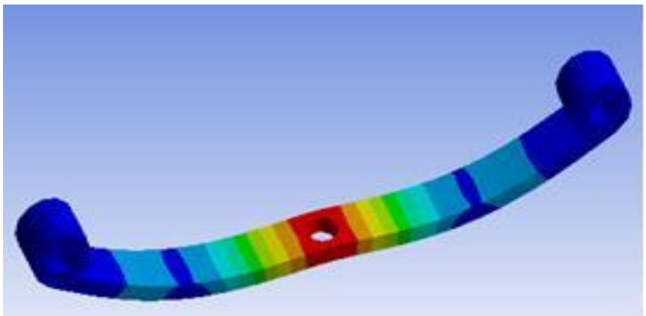

Figure-2: Contour diagram of showing deflection of leaf spring

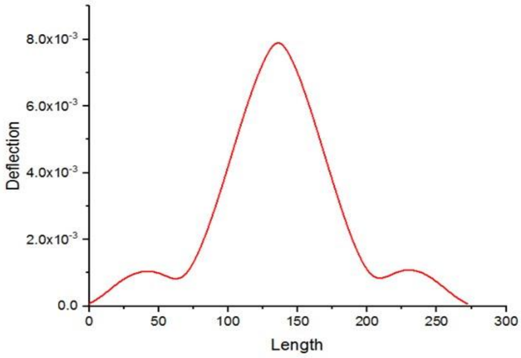

Figure -3: Graph between deflection and total span of leaf spring

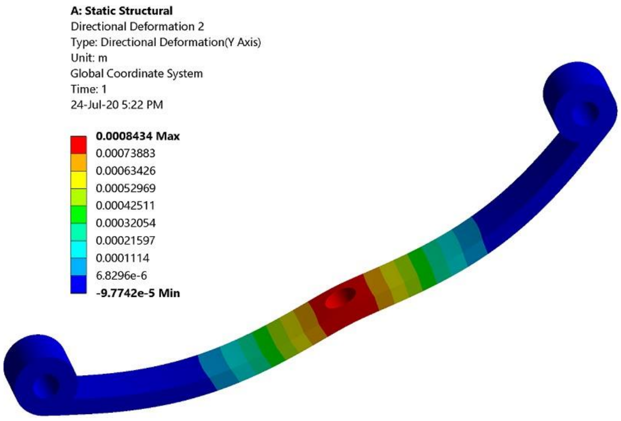

Figure -4: Directional deflection of the mono leaf spring it shows in the X and Y direction deflection

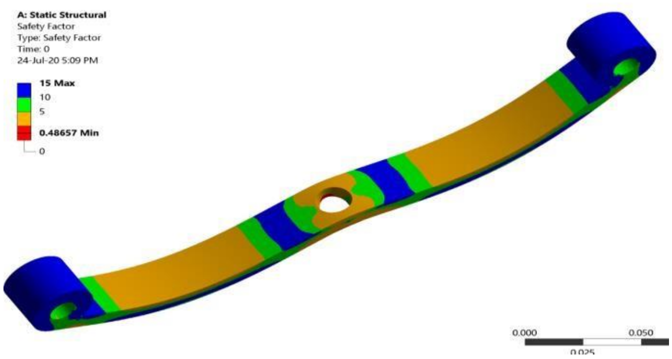

Figure-5.: The factor of safety diagram.

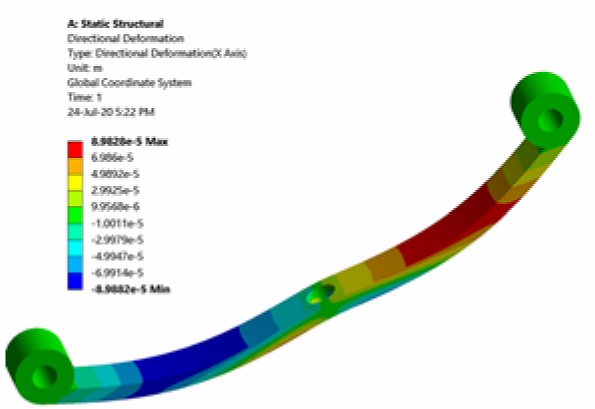

Figure-6. Directional deflection of the mono leaf spring

By applying design load and given boundary condition the factor of safety found by the given load is 5. The below fig shows the factor of safety diagram.

5. DISCUSSION

Though the detailed results are presented in earlier, here an effort is formed to match the results obtained analytically, by FEM and experimentation. For consideration of stresses first equivalent stress is considered.

The detailed discussion is as above. Variation of stress and deflection in graduated leaf spring, the stress is evaluated at whole span.

The results are given in table 2. It is observed from this table that the FE stresses are in good agreement with other literature experimentally calculated stresses with few exceptions. It is also seen that the analytical stress decreases from fixed eye of leaf spring to free end which is very natural from theoretical point of view in which the beam theory is used. But FE analysis revealed that the stress are almost constant in master leaf at the location were the leaf terminate. This find is also confirmed by some experimental literature. This revealed that the maximum stresses in the master leaf are present at many places over its length. This fact was not revealed by analytical analysis. But the analytical analysis revealed the maximum stress of 6.81 MPa nearer to support which is in the range of 5MPa to 15MPa stress calculated by FEM path geometry is used to calculate the value. Though the analytical equation does not give the equal stress at various locations on the master leaf but it can be predict the maximum stress values present in the master leaf variations. The variation in the deflection at various point along master leaf is shown in above figures. which is calculate analytically and by FEM. It is seen from fig. 6 that the nature of variation of deflection is identical.

CONCLUSIONS

In this study, a composite leaf spring system with different material configurations was designed, and the behavior of a composite single leaf spring was studied using a three-dimensional model.

1.From this study it is concluding that though the analytical equation failed to give the maximum stress values in a master leaf away from the support but it is able to letting know the values of maximum stress at the support.

2.But to determine the variation in the stresses at the point away from the support finite element method or experimental technique should be used.

3.In present case the stresses on master leaf cannot fallow cantilever beam theory but when one extra full length leaves are added to the assembly this theory is valid.

4.So, length of graduated leaf plays a significant role in the stresses on master leaf. Hence in actual practice one or two extra full length leaves are wont to strengthen the master leaf.

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