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Design and Numerical Assessment of Composite Leaf Springs for Static Load Performance

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Abstract— *Leaf springs are critical components in automotive suspension systems, providing load-bearing capacity, durability, and ride comfort. Traditional steel leaf springs, while effective, contribute to higher vehicle weight and fuel consumption. This study explores the design and numerical evaluation of composite leaf springs, which offer weight reduction, improved strength-to-weight ratio, and enhanced fatigue life.*
The research focuses on the development of composite leaf springs using materials such as glass fiber-reinforced polymer (GFRP) and carbon fiber-reinforced polymer (CFRP). A finite element analysis (FEA) approach is used to evaluate stress distribution, deflection characteristics, and load-bearing capacity under static loading conditions. The performance of composite springs is compared with conventional steel leaf springs to assess potential weight savings and mechanical advantages.
The results indicate that composite leaf springs exhibit superior strength, reduced weight, and improved flexibility while maintaining adequate load-bearing capacity. This study contributes to the advancement of lightweight and high-performance suspension systems, promoting fuel efficiency and sustainable material applications in the automotive industry.

Keywords— CAD, FEA, Leaf Spring, Heterogeneous

I. INTRODUCTION

1.1 Suspension and Leaf Springs

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. The leaf spring is one of the oldest suspension types. Nowadays it is widely used in heavy duty vehicles and work machines. Sometimes it is also called as a semi-elliptical spring; as it takes the form of a slender arc shaped length of spring steel (Fig.1.1) of rectangular cross section. The center of the arc provides the location for the axle, while the tie holes are provided at either end for attaching to the vehicle body.

Supports the chassis weight, controls chassis roll more efficiently-high rear moment center and wide spring base, controls rear end wrap-up, controls axle damping, controls braking forces and regulates wheelbase lengths (rear steer) under acceleration and braking.

Fig 1: Leaf Springs

1.2 Spring Material Property

The most common leaf spring material used is silicon steel and the properties of the same if given below.

Name	:65Si7 (Isotropic)
Young's modulus (E)	:2.1e5 N/mm2
Poisson's Ratio	:0.266
BHN	:400-425
UTS	:1940 MPa
Tensile strength Yield	:1450 MPa
Spring stiffness	:221.5 N/mm2
Density	:7850 Kg/m3

1.3 Mechanical Properties of Rubber

Rubber is a unique material that is both elastic and viscous. Rubber parts can therefore function as shock and vibration isolators and/or as dampers. Although the term rubber is used rather loosely, it usually refers to the compounded and vulcanized material. In the raw state it is referred to as an elastomer. Vulcanization forms chemical bonds between adjacent elastomer chains and subsequently impart dimensional stability, strength, and resilience. An unvulcanized rubber lacks structural integrity and will "flow" over a period of time. Rubber mechanical properties as follows,

Hardness, shore A	10–90
Tensile strength	11 N/mm²
Elongation at break	100–1100%
Maximum temperature	+300 °C
Minimum temperature	-120 °C
E	9.70e5 N/mm²
Poisson Ratio	0.45

1.4 Rubber Compounding

Typical rubber compound formulations consist of 10 or more ingredients that are added to improve physical properties, affect vulcanization, prevent long-term deterioration, and improve process ability. These ingredients are given in amounts based on a total of 100 parts of the rubber.

1.5 Elastomer

Both natural and synthetic elastomer is available for compounding into rubber products. The American Society for Testing and Materials (ASTM) designation and composition of some common elastomers are shown in Table 1 Some elastomers such as natural rubber, Neoprene, and butyl rubber have high regularity in their backbone structure. They will align and crystallize when a strain is applied, with resulting high tensile properties. Other elastomers do not strain-crystallize and require the addition of reinforcing fillers to obtain adequate tensile strength. Natural rubber is widely used in shock and vibration isolators because of its high resilience (elasticity), high tensile and tear properties, and low cost. Synthetic elastomers have widely varying static and dynamic properties. Compared to natural rubber, some of them have much greater resistance to degradation from heat, oxidation, and hydrocarbon oils. Some, such as butyl rubber, have very low resilience at room temperature and are commonly used in applications requiring high vibration damping. The type of elastomeric used depends on the function of the part and the environment in which the part is placed. Some synthetic elastomers can function under conditions that would be extremely hostile to natural rubber. An initial screening of potential elastomers can be made by determining the upper and lower temperature limit of the environment that the part will operate under. The elastomer must be stable at the upper temperature limit and maintain a given hardness at the lower limit. There is a large increase in hardness when approaching the glass transition temperature. Below this temperature the elastomer becomes a "glassy" solid that will fracture upon impact. Further screening can be done by determining the solvents and gases that the part will be in contact with during normal operation and the dynamic and static physical properties necessary for adequate performance.

1.6 Finite Element Analysis

Traditional approach to design analysis involves the application of classical or analytical techniques. This approach has the following limitations: Stresses and strains are obtained only at macro level. This may result in inappropriate deployment of materials. Micro level information is necessary to optimally allocate material to heavily stressed parts. Adequate information will not be available on critically stressed parts of the components. It may be necessary to make several simplifications and assumptions to design complex components and systems, if design analysis is carried out in the conventional manner.

Manual design is time consuming and prone to errors. Design optimization is tedious and time consuming. FEA is a convenient tool to analyze simple as well as complex structures. The use of finite element analysis is not restricted to mechanical engineering systems alone. FEA finds extensive application in electrical engineering, electronics engineering, micro electro mechanical systems, biomedical engineering etc. In manufacturing, FEA is used in simulation and optimization of manufacturing processes like casting, machining, plastic molding, forging, metal forming, heat treatment, welding etc.

Structural, dynamic, thermal, magnetic potential and fluid flow problems can be handled with ease and accuracy using FEA. FEA was initially developed in 1943 by R. Courant to obtain approximate solution to vibration problems. Turner et al published in 1956 a paper on “Stiffness and Deflection of Complex Structures”. This paper established a broader definition of numerical analysis as a basis of FEA. Initially, finite element analysis programs were mainly written for main frame and mini computers. With the advent of powerful PC’s, the finite element analysis could be carried out with the help of several FEA software packages. Finite element method can be applied to a variety of design problems concerning automobiles, airplanes, missiles, ships, railway coaches and countless other engineering and consumer products.

II. PROBLEM DEFINITION AND PROPOSED SOLUTION

2.1 Problem Description

Leaf springs experience fluctuating loads with static loads of the vehicle and pay loads during its life time cycle. The springs were arranged in concentric arc model where each of them has contact at all loading conditions, the loads are transferred to the vehicle chassis through this contact load transfer, and this causes each leaf members experience the stress under all loading conditions. These leaf springs absorb road loads and shocks. While in riding, continuous change in the road surfaces bumps and pot holes make fluctuation loads in the spring members, this decrease service life of the spring members and in turn the whole system. Minimization of the load absorption between leaf members or minimize contact will increase the life. But, the cost of the new or modified system must be an economical one and in terms of maintenance and replacement. So, there is a strong need for a new and innovative economical stress minimization system.

2.2 Proposed Solution

It is clear that, minimizing contact loading will yield improvement in the service life of the leaf spring system. The literature reviews provides enough guidance in leaf spring dimensional details, static loading details from experiment and finite element analysis. Most of the authors proposed composite material model as a better alternate for the leaf spring system, even though it has advantages in strength and fatigue life, it is nerve an economical model for vehicles in the present situation, more over the manufacturing and serviceability is difficult for them. Considering all these factors, a Hyper elastic material (Synthetic Rubber) as an interleaf between leaf springs is proposed in this project work. Rubber can elongate several hundred times than its original shape and retain the same after loading, this behavior is called Hyper elastic, by introducing this Hyperelastic material between leaf spring members will absorb the loads and stress due them. The behaviors of this proposed heterogeneous model will be evaluated through static analysis and compared with the existing model.

III. MODELLING AND SIMULATION

3.1 Model

The following figures show the solid models of the leaf spring system that is taken for the analysis. The model dimensions are taken from the literature review [5].and tested with the given condition and compared with the experimental results.

Since the eye diameter and U-bolt dimensions are not specified in any of the literature review, the FEA results may vary ± 10% from the actual.

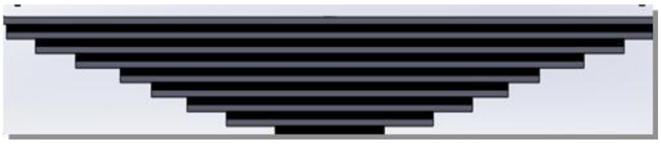

Fig. 2 – Leaf Spring with Rubber Insert Model

Fig. 3- Steel Spring Model

3.2 Leaf Dimension

Length of full length leaves (L-1 and L-2)	:1450 mm each
Width of all leaves	:70mm
Thickness of all leaves	:12mm
No. of extra full length leaf	:1
No. of graduated length leaves	:07
(L-3, L-4, L-5, L-6, L-7, L-8 and L-9)	: 1320,1140,940, 800,640,464,244 mm

3.3 Boundary Conditions

The eyes of the leaf springs are fixed and a static loading of 35000 N, will be applied for static analysis.

3.4 Static Analysis

The following figure shows the imported model of the leaf spring assembly for performing static analysis.

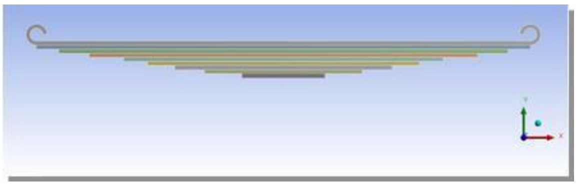

Fig. 4 - Leaf Spring Assembly

The assembly contains 9 leafs, two of them are master leafs and other seven are graduated leafs.

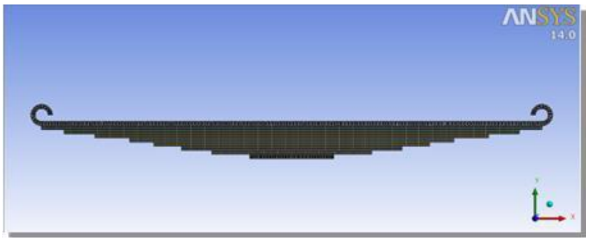

Fig 5 – Mesh

The above figure shows the meshed model of the leaf assembly. It contains 193313 nodes and 47666 elements made of tetra and Hexa type 3d elements. The following figure shows the boundary condition. The master leaf eyes are fixed.

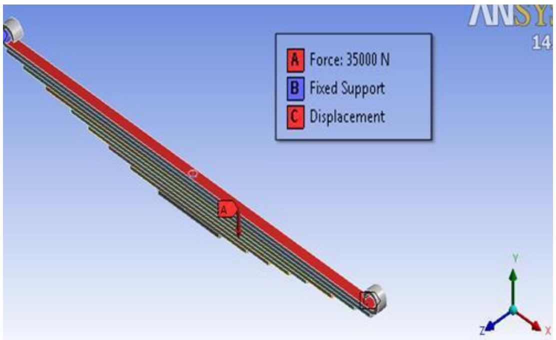

Fig. 6 - Boundary Condition

The following figure shows the loading condition of the model, the static loading of 35000 N is applied on the master leaf spring.

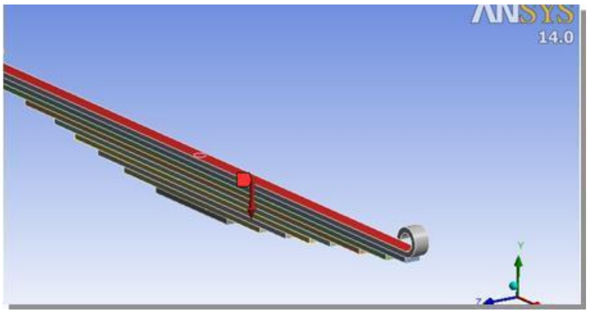

Fig. 7 - Loading Condition

The static loading condition is arrived from the literature reviews, for the same model the load is applied at the master's leaf's top face. When the model is taken cambered the load must be applied at the bottom leaf to simulate the real situation. Here the un-cambered model is taken and applied at the top. The following figure show the maximum deflection that the leaf assembly experience under static loading condition. The maximum value is 156.85 (153 + 3.85) mm.

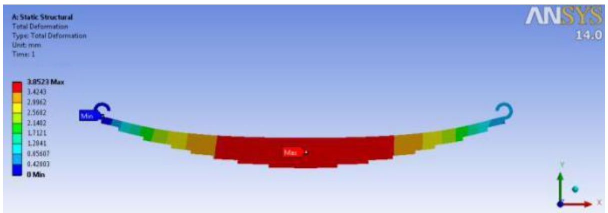

Fig.8- Total Deformation

The following figure shows the VonMises stress of the leaf assembly, it is maximum (1054.1 MPa) at the leaf eyes and it is understandably so, because of the one fixed and one movable ends.

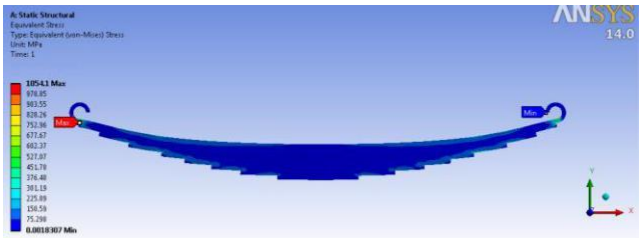

Fig.9 - VonMises Stress

The Tensile stress of the spring material is 1470 MPa which is much higher than the induced VonMises stress.

3.5 Heterogeneous Model Analysis

The following figure shows the heterogeneous model, the model consists of 9 steel leafs, which are interleafed with synthetic rubber. The thickness of the rubber sleeves are same thickness (12 mm) as steel leafs.

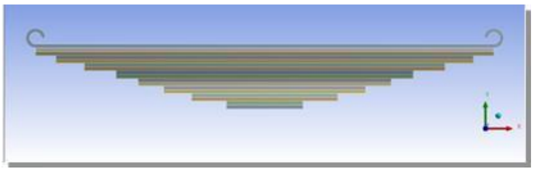

Fig. 10 – Heterogeneous Model

The following figure shows the meshed model, contains 101616 nodes and 118608 elements.

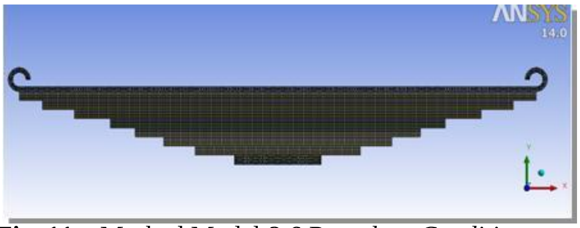

Fig. 11 – Meshed Model

3.6 Boundary Condition

The following figure shows the boundary condition, fixed ends and loading of 35000 N.

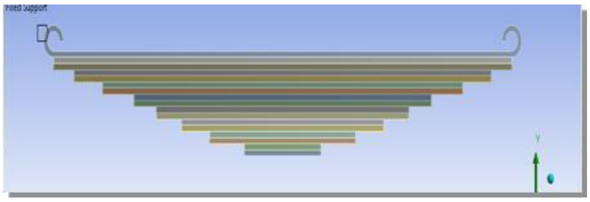

Fig. 12 – Fixed Eye

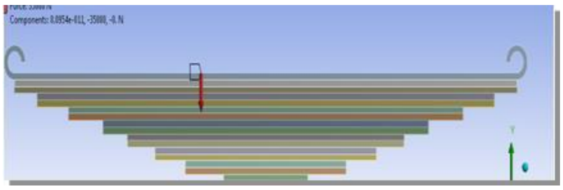

Fig. 13 – Loading

3.7 Results

The following figure shows the VonMises stress. The maximum value shows 146.30 MPa.

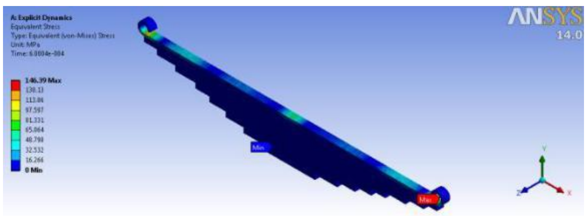

Fig. 14 – VonMises Stress

The following figure shows the maximum shear stress in the model. The value shows 77.722 MPa.

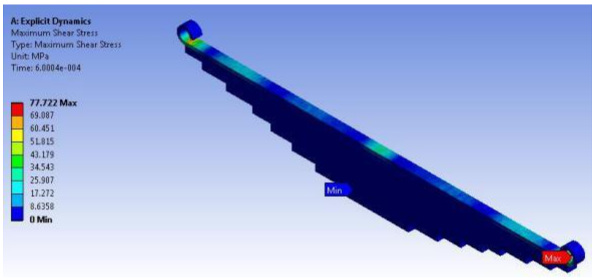

Fig. 15 – Shear Stress

IV. RESULT AND DISCUSSION

4.1 Static Analysis

The static analysis of the steel leaf model shows the following results

Table 1 – Results Comparison

Description	Experimental [5]	FEA	% Difference
Load (N)	35000	35000	0
Max. Stress (MPa)	1018.00	1054.1	+ 10
Deflection (mm)	158.00	156.85	0.7

The result shows that the value gives acceptable nearer results to the experimental result.

4.2 Heterogeneous Model Static Analysis

The following table shows the comparison results of the normal steel and heterogeneous model.

Table 2 – Result Comparison

Description	Steel	Heterogeneous	% Reduction
Load (N)	35000	35000	0
Max. Stress (MPa)	1054	146.30	86.15

Experience a maximum of 1057.3 MPa. The induced is below the yield limit of 1470 MPa.

V. CONCLUSION

Static analysis of steel and heterogeneous leaf springs was numerically investigated and the results show effectiveness of heterogeneous model. From the literature review static loading with specification of leaf spring were extracted and the same is used for modeling the leaf spring. Steel leaf spring is modeled followed by heterogeneous; both were undergone static analysis which shows heterogeneous is far better than steel. The heterogeneous is modeled using silicon rubber leafs inserted between steel leafs provides best result in reducing stress, rubber leafs absorbed around 86% of stress in static loading.

The present research can be extended for experimental investigation to establish a better relationship between analytical, numerical and experimental results. This can be used to form empirical relation among the design parameters of leaf spring.

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