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Design, Analysis and Optimization of a Lightweight Vehicle's Leaf Springs

[1]Dr. Satish M. Silaskar, Assistant Professor, New Horizon Institute of Technology & Management, Thane, India.silaskarsatish@gmail.com

[2]Dr. Sanjay Nikhade . Associate Professor, Jhulelal Institute of Technology, Nagpur, India,sanjaynikahde@rediffmail.com

[3]Pranav Davane ,UG student, New Horizon Institute of Technology &Management Thane,India ,pranavdavane@gmail.com

[4]Pravin Alone, Assistant Professor, New Horizon Institute of Technology & Management, Thane, India, deepakalone@gmail.com

Abstract :In recent years, the automobile industry has primarily concentrated on reducing weight and improving ride quality. Because composite materials have a high strength-to-weight ratio, strong corrosion resistance, and tailorable qualities, Steel leaf springs are being phased out in favour of composite leaf springs in the automotive industry. Three strategies have been investigated to reduce vehicle weight: rationalizing the body structure, using lightweight materials for parts, and reducing vehicle size. This study describes the static and dynamic analysis of steel 55Si2Mn90 parabolic leaf springs as well as composite parabolic leaf springs consisting of E Glass fibre, Carbon fibre, and Kevlar fibre. The goal of this study is to examine the load carrying capability, stiffness, and weight reduction of composite and steel leaf springs. Dimensions of an existing steel 55Si2Mn90 parabolic leaf spring and a light commercial vehicle's composite parabolic leaf spring are taken. In terms of weight and stress developed, a comparison was made between composite and steel leaf springs. The Kevlar fiber leaf spring, after optimization, is 45.67% lower in weight than other materials and has superior riding quality than a typical steel spring with equal design criteria.

Keywords- Leaf spring, composite Material, Analysis, optimization

I. INTRODUCTION

In the current context, research and technology are focused on reducing the weight of automobiles while maintaining high material strength. Customer demand fluctuates on a daily basis. To address this issue, the automobile industry is attempting to develop new vehicles that give great efficiency at a reasonable cost. Weight reduction is primarily done by the use of superior materials, design optimization, and improved manufacturing techniques. Composite has become a very good alternative material for conventional steel due to its ability to reduce weight while improving mechanical qualities. Leaf spring is one of the components of an automobile that may be easily replaced. A leaf spring is a simple type of spring that is widely used for wheeled vehicles' suspension. Leaf springs are a type of suspension mechanism that protects passengers from road shocks. It transfers lateral loads, brake torque, driving torque, and shock absorption system via spring deflections, storing potential energy in a spring before gently releasing it. The tension bar is a well-known example of a basic spring. Because all of its elements are stressed, a tension bar is an efficient energy storage element. If composed of metal, its deformation is minimal. The only common application for it is on bicycle wheel spokes. Machines and a variety of

other applications employ mechanical springs. The force exerted on a spring is proportional to its change in length as it is stretched or compressed. The spring constant of a spring is equal to the change in force put on the spring divided by the change in deflection of the spring.

The relationship between the weights (F) given to a spring and the deflections (δ) determines its performance. If the spring is tightly coiled and the material is elastic enough, the F- δ characteristic is almost linear. The spring stiffness $k = F/\delta$, which is defined by the spring geometry and modulus of rigidity, is the slope of the characteristic.

Flat plates are used to make leaf springs (also known as laminated or carriage springs). It is one of the oldest spring

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types utilized in commercial and heavy-duty vehicles. Leaf springs have an advantage more than helical springs in that they deflect as the spring deflects., the spring's end are steered towards a specified path to serve as a single structural part. In addition to shocks, the leaf springs can handle braking torque, lateral stresses, and driving torque. Figure 1 illustrates the geometry of a leaf spring.

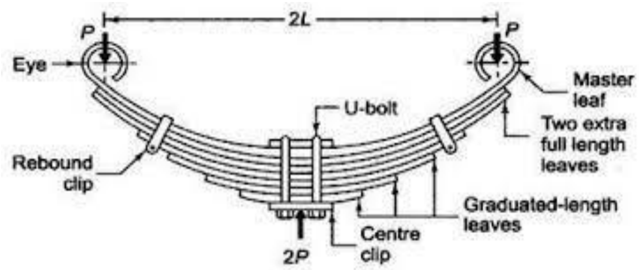

Figure 1: Geometry of leaf spring

II. LITERATURE REVIEW

Vaibhav Edake et.al In this article the author worked on their project to find out the best suited material for the leaf spring under the application of vibration loading. It comprised the study of leaf made with the composite material carbon fiber and comparing its strength and weight with the conventional steel leaf spring. Vibration analysis were applied on the composite spring and therefore the natural frequencies were compared to find out the feasibility of material for the leaf spring. The leaf spring is designed for TATA ACE mini truck suspension leaf spring using standard design procedures. The designed leaf spring is analyzed using ANSYS 16.2 software for the maximum and minimum stress regions. The analysis is carried out on the composite leaf spring produced from carbon fiber. From the result, they concluded that the weight of the conventional leaf spring is 5.53 and that of carbon fiber is 2.87,so the reduction in weight is 48.16% . [1]

Naman Gupta et.al (2018) he stated that, the aim of paper was to represent a general study on design and analysis of leaf spring with reduction in weight. The objective of this paper is to get detail on various spring issues such as compare the load carrying capacities, stiffness and weight saving of two different designs of leaf spring. In addition to, this paper they carried out study of leaf spring on different materials (55Si2Mn90 and 50CrV4). In this paper conventional steel leaf springs of light commercial vehicle are used. They used CREO 2.0 for modelling of both the springs and HYPERWORKS for the analysis of springs. [2]

Syambabu Nutalapati (2015) has worked on rear leaf spring of Mahindra “Commander 650 DI.” The main objective is to compare the stress, deformations and weight reduction of composite leaf spring with that of steel leaf spring. Since the composite materials has high strength to weight ratio, good corrosion resistance, Automobile Industry has great interest for replacement of steel leaf spring with that of composite leaf spring. The material used was glass fiber reinforced polymer (E-glass/epoxy) against conventional steel leaf spring. The weight of composite leaf spring was reduced up to 85% compared with steel material. The leaf spring is modelled in Pro/E and the analysis was done using ANSYS V12.0 software. The fatigue life of both steel and composite leaf are compared using ANSYS software. [3]

Ganesh R. Chavhan, et.al (2018) [4] studied on number of parts which can be replaced by composite material. As composite material has more elastic strength and high strength to weight ratio as compared with those of steel material. For reducing the weight of leaf spring the analysis was carried out on the model of Mahindra Pickup’s leaf spring with existing dimensional geometry. The analysis was carried out on ANSYS V15.0 with loading condition for deflection and bending stress of steel as well as composite materials. A study has been made between steel and composite leaf spring with respect to strength and weight. The results shows that composite leaf spring reduces the weight by 60% for E-glass 21xK43 Gevetex, 74.23% for T300 and 74.82% for AS4 and59.7% Silenka over steel leaf spring. [4]

M. Arther Clive (2018) has stated that Automobile industries has shown their interested in the replacement of conventional leaf spring with composite leaf spring. It has high strength, impact strength and high load bearing capacity. Their main motive was to design and analysis of composite leaf spring. The objective is to compare the equivalent elastic strain, deflection, and equivalent stress of carbon epoxy carbon fiber, E glass epoxy over conventional steel leaf spring. Deflection in the leaf is one of the important properties of the leaf spring. It should have high shock load absorbing capacity and should vertical vibrations due to road abnormalities. The leaf springs was modelled in Auto-CAD 2012 and analysis was done using ANSYS V9.0. By comparisons it has been found that E glass epoxy leaf spring has high deformation than conventional leaf spring.[5]

D. Lydia Mahanthi, et.al (2017) stated that to reduce vehicle weight, there are three techniques that been studied on the body structure, utilizing lightweight materials for parts and decreasing the size of the vehicles. They approached towards composite materials, which is having low cost, high strength to weight ratio and excellent corrosive resistance that can fulfil the requirement. The suspension leaf spring is one of the potential entity for weight reduction in automobiles as it results in large unsprung mass. The introduction of composite material such as fiber reinforced plastics (FRP) is used to reduce the weight of the product without any reduction in load carrying capacity and spring rate. As the materials contains high strain energy storage capacity and high strength-to

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weight ratio compared to steel, multi-leaf springs are replaced by mono-leaf FRP spring. FRP springs has excellent fatigue resistance and durability. [6]

Amitkumar Magdum (2016) studied on the dynamic analysis of the leaf spring as it is the simplest and widely utilized in significant Industrial load carrying vehicles. The leaf spring is a member which acts as an shock absorbing system on the virtue of its deflection. In this paper leaf springs is analysed using finite element methods also considering the dynamic effect on stability of vehicle during cornering, off road drives etc. Considered parameters during the analysis are stiffness of the leaf spring and load acting on leaf spring. It includes the study of stress, deflection, distribution of leaf spring for heavy duty vehicles, considering various recent materials. The composite materials compared are Kevlar Fabric, S-Glass Composite Fiber, Titanium alloy. The paper aims to determine the harmonic response of spring for different materials and loads. Result shows the best suitable material for better dynamic behaviour of leaf spring and its design optimization. [7]

III.MATERIALS AND DESIGN SELECTION

A.Selection of Materials

The cost of a car is 60-70 percent determined by the materials used, hence the performance of the vehicle is improved. Even a great economic impact is caused due to small weight reduction in automobile. Composite material is only materials that can replace steel and help in weight reduction at the same time. So it's best that the leaf spring is made from composite material

Table 1: Properties of E-Glass Fiber, Carbon Fiber and Kevlar Fiber

Sr.No.	Properties	E-Glass epoxy	Carbon Fiber	Kevlar Fiber
1	Young's modulus (E), MPa	25000	70000	30000
2	Material's Ultimate tensile strengthl, MPa	440	600	480
3	The material's ultimate compressive strength, MPa	425	570	190
4	Density of the material (ρ), g/cm^3	1.90	1.60	1.40
5	Poisson's ratio (μ)	0.20	0.10	0.20

B. Choosing a Design

This spring is analogous to a simply supported beam, and flexural analysis on springs is performed with this in mind. Bending and transverse shear stresses are applied to the simply supported beam.. Significant parameter of the leaf spring design is Flexural rigidity.

Design Calculations of Conventional Spring in the Leaves Cantilever Beam is what the Leaf Spring is. As a result, the load operating on each Leaf Spring assembly is also acting on the two ends of the Leaf Spring. Because the Cantilever Beam is taken into account, the load acting on the Leaf Spring is divided in two.

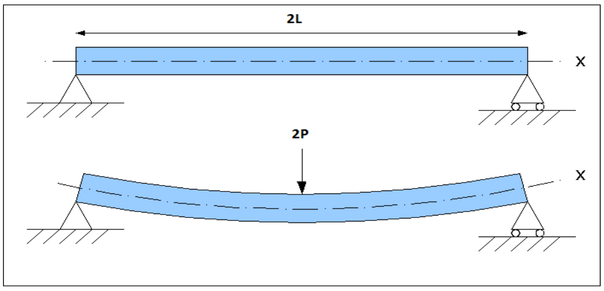

Figure 2: simply supported beam, having a central load of 2P

IV.3D MODELING AND FINITE ELEMENT ANALYSIS

A.Solid Modeling

A solid model is a digital depiction of the geometry of a real-world or created object. The majority of the time, the design process is iterative. Points, curves, and surfaces can be specified and stitched together to define electronic representations of an object's border. The outcome is a digital approximation of the geometry of an object or an assembly of objects that is unambiguous, full, and detailed.

Modelling of leaf spring is done by PTC CREO. Leaf spring which is to be modelled is having a constant cross section area, varying lengthwise thickness and breadth Hence it is not possible to generate mono composite leaf spring directly

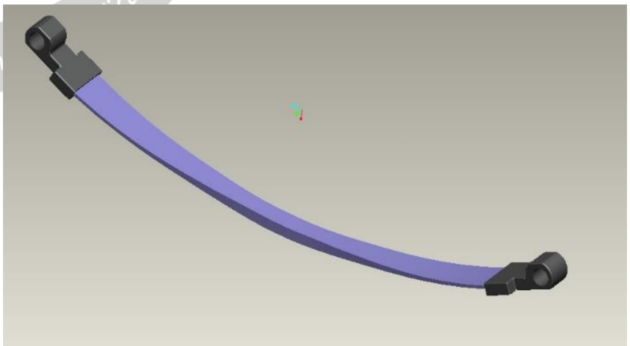

Figure 3. Three Dimensional Model of Leaf Spring

B. Analysis of a Composite Leaf Spring Using Finite Element Methodology.

3D finite element analysis is used to examine the composite leaf spring's static strength, deflection.. The current study makes use of the ANSYS 21.0 general-purpose programme for calculating finite elements. The

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composite leaf spring is modelled in PTC CREO was imported into ANSYS 21.0

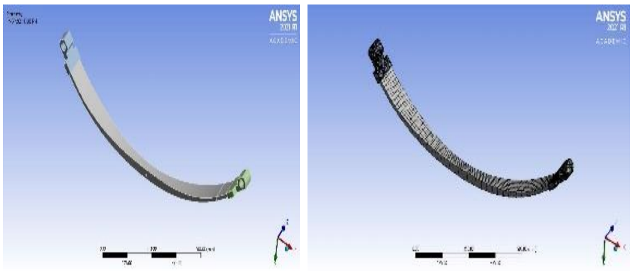


Figure 4: Modeling and Meshing of The leaf spring

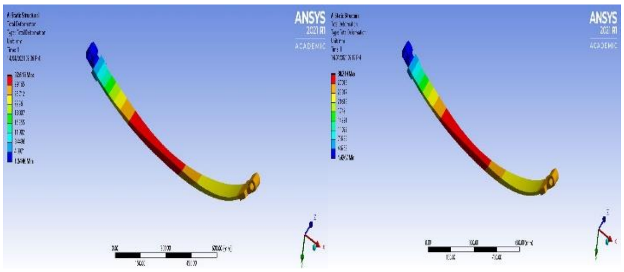


Figure 5 .Deflection of Kevlar Fiber and E-Glass Fiber for maximum static load

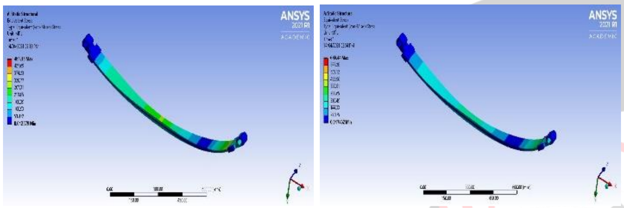


Figure 6. Stress develop Kevlar Fiber and E-Glass Fiber for maximum static load

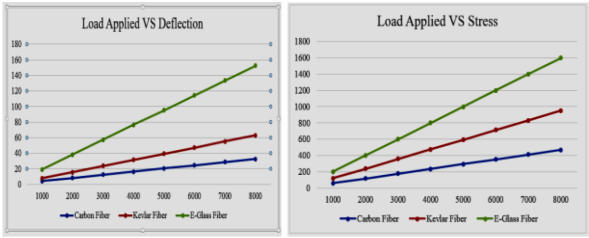
C. Results for Different Loads

Table 2: Deflection at different loads (static)

Load Applied (N)	Deflection (mm) E-Glass Fiber	Carbon Fiber	Kevlar Fiber
1000	11.201	4.077	3.776
2000	22.403	8.154	7.553
3000	33.604	12.231	11.330
4000	44.805	16.309	15.107
5000	56.005	20.386	18.884
6000	67.208	24.463	22.660
7000	78.409	28.540	26.437
8000	89.610	32.617	30.214

Table 3: stress at different loads (static)

Load Applied (N)	Stress (N/Mm^2) Carbon Fiber	Kevlar Fiber	Glass Fiber
1000	58.62	60.14	81.18
2000	117.24	120.29	162.36
3000	175.87	180.43	243.54
4000	234.49	240.57	324.72
5000	293.11	300.72	405.90
6000	351.73	360.86	487.08
7000	410.35	421.01	568.26
8000	468.97	481.15	649.44



Graph 1: Load verses deflection and Stress develop (Static)

V. DYNAMIC ANALYSIS

The Dynamic Analysis also carried out on composite mono leaf spring in ANSYS software. The Load is applied with respect to time. The reaction of a structure subjected to a time-sensetive stress, taking into account inertia and damping effects, is determined using a transient dynamic analysis.. The complete technique or the modal superposition approach can be used to perform a time-transient analysis in ANSYS Workbench. To calculate the transient response at each point, the full method employs the whole system matrix.

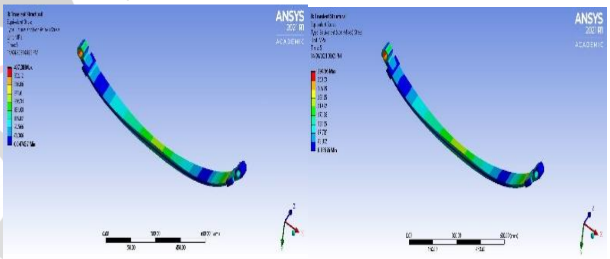


Figure 7: Dynamic Stress induced in Kevlar Fiber and Carbon Fiber

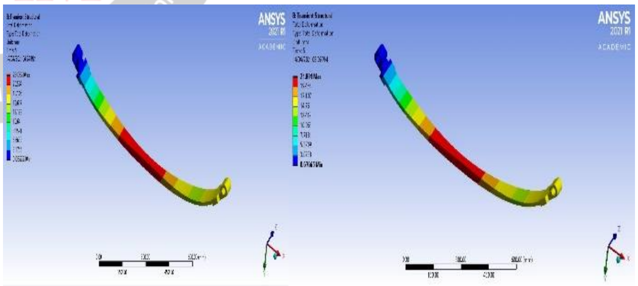


Figure 8: Deflection in Kevlar Fiber and Carbon Fiber during Dynamic Analysis

A. Stress and Deflection at different loads (Transient Dynamic Loading)

Table 4: Deflection at different loads (Transient Dynamic Loading)

Load Applied (N)	Deflection (mm) Carbon Fiber	Kevlar Fiber	Glass Fiber
1000	3.945	3.685	8.696
2000	7.310	6.885	15.363

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3000	10.281	9.716	21.625
4000	13.033	12.33	27.724
5000	15.654	14.81	33.729
6000	18.187	17.198	39.683
7000	20.657	19.522	45.604
8000	23.082	21.801	51.497

Table 5: Stress at different loads (Transient Dynamic Loading)

Load Applied (N)	Stress (N/mm^2)		
	Carbon Fiber	Kevlar Fiber	Glass Fiber
1000	54.842	52.697	81.249
2000	105.76	102.08	163.75
3000	153.95	148.86	236.37
4000	200.62	194.13	302.91
5000	251.51	240.06	365.29
6000	305.15	293.1	424.51
7000	357.04	344.55	481.24
8000	407.38	394.56	535.94

B.COMPARISON OF WEIGHT AND DEFORMATION

Material	Stress (Mpa)	Deformation (Mm)	Weight (Kg)	Weight Reduction (%)
55Si2Mn90	522.24	89.560	28.49	-
Carbon Fiber	468.97	32.617	17.53	37.92
Kevlar Fiber	481.15	30.214	15.34	45.67
E-Glass Epoxy	649.44	89.610	20.82	28.18

VI. CONCLUSION

1. Static structural analysis was carried out on both steel and composite leaf springs. Composite leaf springs and steel leaf springs with the same design and load carrying capacity were compared

2. Total deformation, equivalent elastic strain, equivalent (von-mises) stress, strain energy and mass results have been analyzed for different material combination in different design cases of leaf spring.

3. PTC creo 2.0 is used for 3d modeling of leaf spring and Stress and displacements were calculated analytically and using ANSYS for steel and composite leaf springs, respectively**.**

4. Results for selected parameters are obtained for all design cases of leaf spring.

5. Deflection, stress analysis and load analysis has been carried out and the result are satisfactory. Weight reduction of 37.92%, 45.67%, and 28.18% is obtained in material such as carbon fiber, kevlar fiber and e-glass epoxy respectively when compared with 55si2mn90.

6. As a result, the goal of minimizing unsprung mass is realised to a greater extent. Hence, best material that can be used is Kevlar Fiber instead of 55Si2Mn90 for light weight vehicle.

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