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Design and Analysis of Composite Parabolic Leaf Spring

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ABSTRACT

The abstract summarizes the key aspects of the design and analysis of a composite parabolic leaf spring. This study encompasses the comprehensive process of material selection, geometric design, and structural analysis to ensure optimal performance and durability. Utilizing finite element analysis (FEA), stress analysis, fatigue analysis, and buckling analysis, the leaf spring's behavior under varying loading conditions is thoroughly examined. Iterative optimization based on analysis results enables the refinement of the design, balancing factors such as weight reduction and performance enhancement. Prototyping and physical testing validate the simulation data, affirming the reliability of the design. Manufacturing considerations and integration into the intended application are essential aspects, emphasizing cost-effectiveness and alignment with performance requirements. Establishment of a monitoring and maintenance protocol ensures sustained functionality and safety throughout the leaf spring's operational lifespan. This abstract encapsulates the comprehensive approach undertaken to develop a robust composite parabolic leaf spring for various engineering applications.

Keywords: Design, Analysis, Composite, Parabolic, Leaf Spring, Engineering

1. INTRODUCTION

In the contemporary automotive industry, the pursuit of natural resource conservation and energy efficiency has driven a concerted effort towards weight reduction and increased deflection capabilities. Traditional leaf springs, while prevalent in vehicle suspension systems, have been plagued by deflection issues. Composite leaf springs offer a promising solution, boasting superior deflection characteristics compared to their conventional counterparts and thereby facilitating vehicle weight reduction.

Weight reduction strategies, including the adoption of advanced materials, optimized designs, and enhanced manufacturing processes, hold the key to achieving improved fuel efficiency and driving dynamics. The leaf spring, constituting a significant portion of the unsprung weight in automobiles, presents a prime target for such enhancements.

The advent of composite materials has revolutionized leaf spring design by enabling substantial weight reductions without compromising load-carrying capacity or stiffness. Composite materials exhibit superior elasticity, energy storage capacity, and strength-to-weight ratios compared to traditional steel, leading to the gradual replacement of multi-leaf steel springs with mono-leaf composite counterparts. However, while composite leaf springs offer significant weight-saving opportunities, their cost-effectiveness relative to steel remains a consideration.

Functionally, leaf springs serve as elastic bodies that absorb vehicle vibrations, shocks, and road-induced loads by deflecting and gradually releasing stored strain energy. Semi-elliptic leaf springs, prevalent in both light and heavy commercial vehicles, are characterized by a series of blades bound together and mounted on the vehicle's axle. This introduction sets the stage for a comprehensive examination of composite parabolic leaf springs and their role in modern automotive suspension systems.

2. OBJECTIVES

- Investigate the feasibility of utilizing composite materials in the design of parabolic leaf springs.
- Assess the potential for weight reduction in automotive leaf spring applications through composite material adoption.
- Analyze the deflection characteristics of composite parabolic leaf springs compared to traditional steel leaf springs.
- Optimize the design parameters of composite parabolic leaf springs to achieve desired performance metrics.
- Evaluate the structural integrity and durability of composite parabolic leaf springs under various loading conditions.

- Compare the cost-effectiveness of composite parabolic leaf springs with their steel counterparts.
- Explore the potential for improved fuel efficiency and driving dynamics through the implementation of composite parabolic leaf springs in automotive suspension systems.

3. METHODOLOGY

- Conduct literature review on existing research and advancements in composite leaf spring design and analysis.
- Define material properties and characteristics of composite materials suitable for leaf spring applications.
- Develop numerical models using finite element analysis (FEA) software to simulate the behavior of composite parabolic leaf springs under various loading conditions.
- Perform stress analysis, fatigue analysis, and buckling analysis to evaluate the structural performance and durability of the composite leaf springs.
- Iteratively optimize the design parameters including material layup, thickness distribution, and geometry based on analysis results.
- Fabricate prototypes of the composite parabolic leaf springs using appropriate manufacturing processes such as resin infusion or filament winding.
- Conduct physical testing on the prototypes to validate the simulation data and assess real-world performance.
- Compare the experimental results with simulation data to verify the accuracy of the numerical models.
- Analyze the cost-effectiveness of composite parabolic leaf springs compared to traditional steel leaf springs.
- Summarize findings and draw conclusions regarding the feasibility and effectiveness of composite parabolic leaf springs in automotive suspension systems.

4. LEAF SPRING

The leaf spring supports the weight of the entire vehicle. A straightforward pin joint connects the spring's front end to the frame, and a shackle connects the spring's back end to the frame. The flexible piece that joins the leaf spring rear eye and frame is called the shaker. The wheel moves up in response to a projection on the road surface, which causes the spring to deflect. The space between the spring eyes is altered as a result.

The spring will not be able to adapt to this change in length if both ends are fixed. Therefore, a shackle is given at one end to accommodate this change in length, providing a flexible connection.

While the back eye of the leaf spring is unconstrained in the X-direction, the front eye is restricted in all directions. The shackle is attached to this unusual eye.

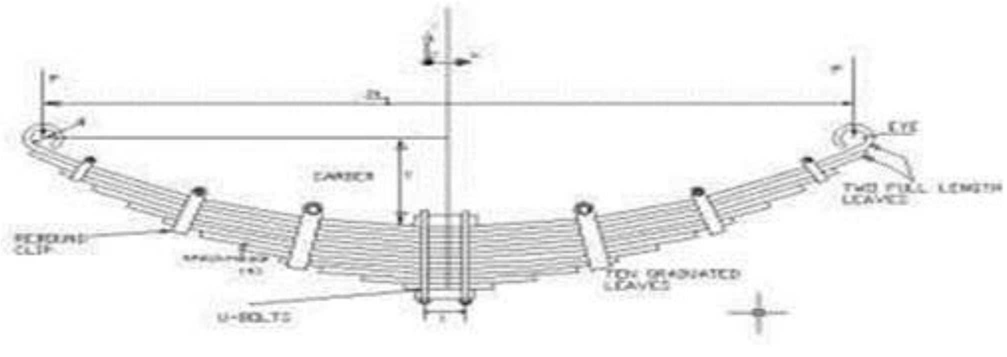

Fig 1: leaf spring

5. WORK FLOW PROCESS

5.1 MIXING SOLUTION

- CARBON
- Epoxy Resin
- Graphite Material

- Hardener

SI NO	**MIXING COMPONENTS**	**QUANTITY**
1	Carbon	300g
2	Epoxy resin	1kg
3	graphite material	500 g
4	Hardener	800g

5.2 MIXING COMPONENT SOLUTION MAKING PROCESS

We have 800 g of hardener combined with 500 g of recycled plastic, 1 kilogram of epoxy solution, and 300 g of carbon powder. To create a bonded solid, they are combined with epoxy and a hardening solution. The epoxy hardener solution is to be combined with plastics and carbon. After combining the mixture, they all put it into a spherical, elastic plastic jar.

DESIGN DATA DETAILS

Here Weight and initial measurements of Mahindra Model - 650 light vehicle are taken

Gross vehicle weight = 2150 kg

Un sprung weight = 240 kg

Total sprung weight = 1910 kg

Taking factor of safety (FS) = 1.4

Acceleration due to gravity (g) = 10 m/s²

There for; Total Weight (W) = 1910*10*1.4 = 26740 N

6. RESULT AND IDSCUSSION

MATERIAL PROPERTIES OF CARBON EPOXY

Density	1.6e-009 tonne mm^-3
Young modulus MPa	1.75e+005
Poisson’s ratio	0.3
Bulk modulus MPa	1.416e+005
Shear modulus MPa	65385

CARBON EPOXY LEAF SPRINGS – RESULT

MATERIAL OF CARBON

CARBON EPOXY	MINIMUM	MAXIMUM
Total deformation	0	0.20123
Equivalent elastic strain	3.2392e-008	3.4765e-004
Equivalent stress	2.9358e-003	58.721

Density	6.3e-018 tonne mm^-3
Young modulus MPa	2.75e+005

Poisson’s ratio	0.34
Bulk modulus MPa	2.8646e+005
Shear modulus MPa	1.0261e+005

E GLASSEPOXY LEAF SPRING

Density	2.6e-018 tonnemm^-3
YoungmodulusMPa	6530
Poisson’sratio	0.217
BulkmodulusMPa	3845.7
Shear modulusMPa	2682.8

RESULT COMPARISON OF ALL LEAF SPRINGS

leaf spring type	Total deformation	Equivalent elastic strain	Equivalent stress
conventional	0.167	0.0002897	58.72
Carbonepoxy	0.20123	3.4765e-004	58.721
carbon fiber l	0.12421	2.1544e-004	58.848
E glass epoxy	5.2444	8.9891e-003	58.348

EXPERIMENTAL RESULTS TABLES

Load	**Deformation**		**Displacement**		
(N) (mm)				**(mm)**	
	E glass /	**Carbon/**	**E glass**	**Carbon/**	**graphite**
Epoxy Epoxy			**/Epoxy**	**Epoxy**	**epoxy**
1500	1.605	3.45	12.7661	87.3178	**2120.6**
3000	1.606	7.08	25.5323	174.636	**4241.2**
4500	1.716	10.63	63.6181	261.953	**1130**
6000	1.824	14.72	84.8242	349.273	**1506**

Load Strain **(N) (MJ)**				**Stress** **(N/mm2)**		
E glass /		Carbon/ Epoxy	graphite epoxy	E glass /Epoxy	Carbon/ Epoxy	**graphite** **epoxy**
	Epoxy					
1500	0.80	5.879	1.36	238052	252626	**241082**
3000	1.61	11.75	2.73	476103	505252	**482163**
4500	4.08	17.63	0.755	723245	757878	**750267**
6000	5.44	23.51	1.007	964327	1x10^{6}	**1x10^{7}**

Load (N)	**Deformation Re Design leaf spring (mm)**		**Deformation Normal leaf spring (mm)**	
1500	E glass /Epoxy 1.605	Carbon/Epoxy 3.45	E glass /Epoxy 1.872	Carbon/Epox y3.983
3000	1.606	7.08	1.923	7.571
4500	1.716	10.63	2.471	11.340
6000	1.824	14.72	2.613	15.782

The mode shape as can be seen from figure 2 natural frequency increase slightly with load increase to maximum value load at 6000N.the deformation curve constant value at all load condition but minimum variations at all load. The result shows when load increases the natural frequency increased The mode shape as can be seen from figure 8.12 natural frequency increase slightly with load increase to maximum value load at6000 N. the deformation curve constant value at all load condition but minimum variations at all load. The result shows when load increases the natural frequency increase. The maximum displacement of the leaf spring to compare load and maximum displacement as can be seen from figure 8.13 load slightly with increase to maximum value load at 6000N.the displacement curve minimum increase at all load condition but minimum variations at all load. the result shows the when load increases the displacement increased.

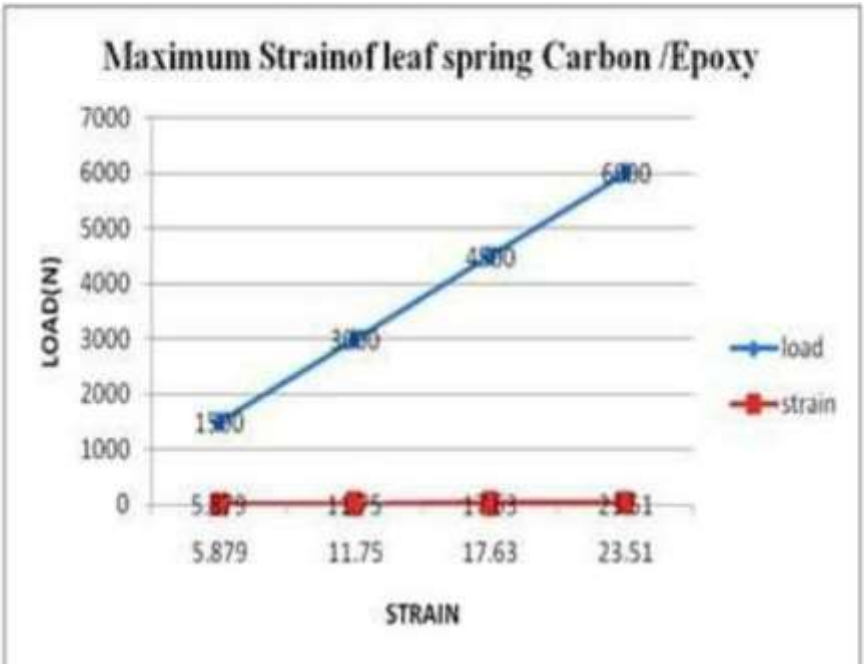

Fig 2: graphs for strain

CONCLUSION

In this comparative study, conventional all-leaf springs were evaluated alongside composite leaf springs constructed from various materials including carbon epoxy, carbon fiber, and glass epoxy, with a focus on their deflection characteristics. Among these materials, E-glass epoxy emerged as the most promising option, displaying superior deformation properties. This finding suggests that E-glass epoxy composite leaf springs could offer significant advantages over conventional steel leaf springs in terms of flexibility and resilience under load.

Moreover, the analysis revealed several key benefits associated with composite leaf springs. One notable advantage is the reduction in friction coefficient and wear rate compared to conventional leaf springs. This reduction can lead to lower maintenance requirements and extended service life, translating into cost savings for vehicle owners and operators. Additionally, composite leaf springs exhibit increased strength and fatigue life, enhancing their overall reliability and durability in demanding operating conditions. These improvements contribute to improved vehicle performance, safety, and longevity.

The findings of this study underscore the potential of composite materials to revolutionize leaf spring design and performance in automotive suspension systems. By leveraging the unique properties of composite materials, such as high strength-to-weight ratio and corrosion resistance, engineers can develop leaf springs that are lighter, stronger, and more durable than their traditional counterparts. This, in turn, can lead to significant benefits for vehicle manufacturers and end-users, including enhanced fuel efficiency, reduced emissions, and improved ride comfort.

Looking ahead, further research and development in composite materials and manufacturing processes hold promise for continued advancements in leaf spring technology. By exploring new materials, fabrication techniques, and design approaches, engineers can unlock even greater performance gains and cost efficiencies, paving the way for the widespread adoption of composite leaf springs in future vehicles. Ultimately, this research contributes to the ongoing evolution of automotive suspension systems, driving innovation and progress in the quest for more efficient, sustainable transportation solutions.

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