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Comparison of Conventional and Composite leaf Spring of E-Rickshaws for Urban India: Study Based Approach

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Abstract: The widespread integration of electric rickshaws (E-Rickshaws) into India's urban and semi-urban transport ecosystems presents a timely opportunity to re-examine critical mechanical components for performance, reliability, and economic efficiency. Among these, the suspension system and more specifically the leaf spring plays a pivotal role in ensuring ride comfort, structural resilience, and long-term operational viability. Most E-Rickshaws currently in operation use conventional EN45 steel leaf springs, which, while cost-effective, pose limitations in terms of weight, fatigue resistance, and maintenance frequency, particularly under the demanding conditions of Indian roads. This study explores the potential benefits of retrofitting E-Rickshaws with composite leaf springs made from Glass Fiber Reinforced Polymer (GFRP). The design and analysis of the EN45 steel multi-leaf spring and the GFRP composite mono-leaf spring are presented in this study. Comparing the strength, working performance, weight savings etcof composite leaf springs vs steel leaf springs is the aim of this paper. The leaf spring was made specifically for the three-wheeled E-rickshaw. In addition to mechanical analysis, a detailed cost-performance assessment was conducted. The study found that lower maintenance needs, weight reduction and enhanced mechanical reliability could offset the upfront investment over time. The reduced unsprung mass was also identified as a factor likely to enhance ride quality and potentially improve energy efficiency in battery-powered vehicles.

Keywords:*E-Rickshaw, Leaf Spring, EN 45 steel, GFRP Composite.*

Introduction

India's urban transportation landscape has undergone a significant shift in the last decade with the rise of Electric Rickshaws (E-Rickshaws), offering an affordable, low-emission, and energy-efficient alternative for last-mile connectivity. As of recent reports, over two million E-Rickshaws operate across Indian cities, especially in tier-II and tier-III urban areas where the need for low-cost public mobility solutions is particularly acute (NITI Aayog& Rocky Mountain Institute, 2019). Despite their economic appeal, the technical configuration of these vehicles has remained largely conventional, particularly in terms of the suspension system, which continues to rely on multi-leaf steel springs adapted from legacy designs used in internal combustion engine (ICE) three-wheelers (Sarkar et al., 2022).

The suspension system in an E-Rickshaw is more than a ride-comfort component; it also directly impacts chassis durability, battery enclosure stability, and long-term maintenance cycles. Given the stop-start nature of urban traffic, the frequent overloading practices, and the poor road infrastructure in many Indian cities, E-Rickshaw suspension systems are subjected to repeated dynamic stresses and fatigue loads (Kumar et al., 2021). Conventional EN45 steel leaf springs, though time-tested, are susceptible to issues like corrosion, excessive sagging, and stress concentration problems exacerbated by the lack of shock absorbers in many budget E-Rickshaw models (Verma et al., 2020). These concerns prompt a necessary investigation into alternative spring materials that can improve both vehicle performance and economic viability.

In recent years, the automotive sector has witnessed a gradual transition from traditional metallic materials to advanced composites, particularly for components like leaf springs that benefit from high strength-to-weight ratios (Rao et al., 2018; Gupta et al., 2020). Glass Fiber Reinforced Polymer (GFRP), in particular, has demonstrated favorable mechanical behavior including superior fatigue resistance, corrosion tolerance, and the ability to distribute stress more uniformly across the structure (Patel et al., 2019). Several studies in light commercial vehicles and passenger cars have validated the use of composite springs through simulations and limited field trials (Sharma et al., 2021; Ahmed et al., 2023). However, the retrofitting of such materials into E-Rickshaws remains relatively underexplored, particularly in the Indian context where cost sensitivity is paramount and operational conditions are uniquely challenging.

The study incorporates a cost performance model to estimate the economic trade-offs involved, factoring in material costs, fabrication complexity, and projected maintenance savings.

By aligning engineering simulations with contextual cost realities, this paper aims to provide a practical foundation for stakeholders including manufacturers, fleet operators, and urban mobility plannerswho are exploring sustainable retrofitting solutions for E-Rickshaws. The findings suggest that while composite leaf springs may incur a modest upfront cost increase, their performance benefits and lifecycle savings make them a compelling alternative in highutilization urban environments.

Literature Review

GS et al., (2024) Steel leaf springs (SLS) are widely used in heavy-duty vehicles due to their strength, load-bearing capacity, and ease of maintenance. However, they contribute significantly to the vehicle's overall weight, which can affect fuel efficiency and ride comfort. A comparative analysis using ANSYS software shows that Glass Fiber Reinforced Epoxy Composite Leaf Springs (GECLS) offer a promising alternative, achieving a weight reduction of 75.32% compared to traditional steel springs. The GECLS also demonstrated higher deflection (4.659 mm)**,** natural frequency (29.98 Hz)**,** and strain energy (440.68 mJ), indicating better vibration isolation and ride quality. In contrast, the steel spring showed higher stress (283.84

MPa) and mass (3.77 kg), which can lead to reduced efficiency and increased wear. These findings suggest that composite leaf springs can provide improved stiffness, reduced resonance risk, and enhanced overall vehicle performance.

Pankaj Saini, Ashish Goel, and Dushyant Kumar[2013] conducted a study on the design and analysis of composite leaf springs for light vehicles, aiming to reduce weight and improve performance compared to traditional steel springs. They evaluated three composite materials—E-glass/epoxy, carbon/epoxy, and graphite/epoxy—using static analysis. The results showed significant weight reductions: 81.22% for E-glass/epoxy, 90.51% for carbon/epoxy, and 91.95% for graphite/epoxy. While most composites experienced lower stress than steel, graphite/epoxy showed slightly higher stress. The study concluded that E-glass/epoxy is the most suitable replacement for steel due to its optimal balance of strength and weight savings.

Manas Patnaik and Narendra Yadav (2012) studied the behavior of a mono parabolic leaf spring for a 1-ton mini loader truck using finite element analysis (FEA) and design of experiments (DOE). They modeled the spring in CATIA V5 R20, varying eye distance and camber depth as input parameters, while observing von Mises stress and displacement as outputs. Key findings from DOE showed that Increasing camber reduces displacement but increases stress And increasing eye distance raises both displacement and stress.

Gupta, R., Kumar, A., and Singh (2020) studied the use of Glass Fiber Reinforced Polymer (GFRP) and Carbon Fiber Reinforced Polymer (CFRP), two widely researched composite materials. Their findings highlight that these composites can reduce component weight by up to 60% while maintaining or even improving mechanical performance.

Patel, N., Desai, M., & Joshi(2018)presented a comparative study of GFRP and steel leaf springs in commercial vans, showing a 20–25% improvement in fatigue life and a 30% reduction in unsprung mass. Simulated composite spring behavior under various loading conditions and confirmed more uniform stress distribution, reduced deflection, and minimal permanent deformation. While such studies validate the viability of composites in passenger and utility vehicles, few have addressed the adaptation of these technologies to ultra-light electric vehicles like E-Rickshaws.

Sharma, A., Verma, S., & Joshi (2022) studied how Finite Element Analysis (FEA) has become the standard method for testing and optimizing suspension components prior to physical prototyping. FEA enables detailed visualization of stress, strain, deformation, and failure risks under controlled virtual conditions.

Yadav, S., and Prakash, R. (2020) conducted a modal analysis using Finite Element Analysis (FEA) to study the natural frequencies of suspension components, aiming to prevent resonance-related failures.

This is particularly crucial for electric vehicles, which undergo frequent start-stop cycles and rapid accelerations. However, the study highlights a gap in integrating such simulation techniques with real-world, context-specific scenarios, especially for E-Rickshaws operating under India's unique road and usage conditions.

Gaps Identified

The existing body of literature provides strong evidence for the mechanical superiority of composite materials in leaf spring applications, and the effectiveness of FEA as a simulation tool for their evaluation. However, a contextspecific approach that applies these insights to E-Rickshaws focusing on urban Indian road conditions, passenger loading patterns, and cost sensitivity remains underdeveloped. This study aims to fill this gap by combining simulation driven design evaluation with a practical cost performance assessment, tailored to the Indian E-Rickshaw segment.

Methodology

Evaluating the practical viability of retrofitting composite leaf springs in Indian electric rickshaws (E-Rickshaws) requires a systematic framework that integrates cost analysis with projected durability outcomes. Given that E-Rickshaws operate in cost sensitive urban markets characterized by harsh road conditions, high frequency of stop-start driving, and frequent overloading, any proposed design improvement must be economically justifiable and mechanically resilient over time.

The following framework outlines a two-pronged approach:

(1) Cost Assessment focusing on material and manufacturing inputs

(2) Durability Estimation derived from simulation based stress analysis.

Figure 1: Multi Leaf Spring

Figure 2: Mono Leaf Spring

Cost Assessment

The cost assessment methodology involves a comparative estimation of total production cost per unit spring for both the conventional EN45 steel leaf spring and the proposed GFRP composite variant. The analysis considers material procurement, fabrication complexity, tooling, and assembly requirements.

Material Cost Comparison

Material costs were calculated using real-time pricing data obtained from Indian raw material suppliers as of early 2025. The table below summarizes the unit cost differences

Table 1:Material Cost Comparison of EN45 Steel spring and GFRP Material

Material	App. Cost (INR/kg)	Density (kg/m³)	Volume per Spring (m³)	Total Material Cost (INR)
EN45 Spring Steel	110	7800	0.00145	1243
GFRP (Glass Fiber Reinforced)	290	2100	0.00160	974

Although the GFRP unit price per kg is significantly higher, its lower density results in a reduced total weight and volume, partially offsetting material expenses.

Manufacturing Cost Consideration

Steel springs involve processes such as hot forming, tempering, and multi-leaf assembly, which are well-established in Indian manufacturing but labor intensive. In contrast, GFRP springs require precision mold based layup and curing potentially more expensive upfront due to equipment and controlled environmental requirements. However, for mid scale production, the cost differential narrows due to lower part count (mono-leaf vs. multi-leaf) and less post-processing.

Table 2Manufacturing CostComparison of EN45 Steel spring and GFRP Material

Process Stage	Steel Spring (Appr. Rs)	Composite Spring (Appr. Rs)
Raw Material	1243	974
Forming & Assembly	450	620
Finishing & QC	180	220
Total Estimated Cost	**1873**	**1814**

This estimation suggests a near equivalent cost for small batch production, with potential for cost reduction in composites at higher volumes due to process repeatability and automation.

Lifecycle Cost Implications

While the upfront cost of composite springs may appear comparable or slightly higher, their expected lifecycle offers economic advantages:

- Reduced maintenance frequency due to corrosion resistance.
- Weight savings contributing to lower battery consumption.
- Lower risk of breakage or interleaf friction wear, common in steel multi-leaf setups.

Some factors in leaf spring is spring replacement frequency, maintenance downtime, and energy cost savings. Preliminary projections estimate a 15–18% cost advantage in favor of GFRP springs over the full lifecycle.

Table3: Comparison of Structural Performance between Baseline Steel and Composite Leaf Springs

Parameter	**Steel Leaf Spring (EN45)**	**Composite Leaf Spring (GFRP)**
Mass	Higher	lighter
Number of Leaves	6	1 (mono-leaf)
Peak Stress Location	Near bolt hole (center span)	At curvature apex
Contact Loss or Interleaf Friction	Present	Absent
Corrosion Resistance	Low (prone to rust)	Excellent
Load Distribution	Uneven due to friction	Uniform due to monolithic build
Manufacturing Complexity	Medium (machining + assembly)	Low (hand lay-up)

Table 4: Summary of the Assessment Framework

Parameter	**Steel Spring**	**GFRP Composite Spring**
Material Cost	Moderate	Higher per kg, less volume
Manufacturing Complexity	Moderate	High (initial), scalable
Mass	Higher	lighter

Results

Weight Comparison

Replacing conventional EN45 steel with GFRP composite material for the leaf spring leads to a noticeable reduction in weight—estimated between 50% and 80%, depending on the design and thickness. This drop in unsprung mass improves the overall performance of the E-Rickshaw. It results in better ride comfort, improved handling, and higher energy efficiency, which is especially important for electric vehicles where every kilogram impacts battery range and performance.

Cost Analysis

Although GFRP composites have a higher per-kilogram cost compared to steel, the total material cost per spring is lower due to the reduced volume and weight required. In small-scale production, the overall manufacturing cost of a composite spring is found to be comparable to that of a steel spring. This is because GFRP mono-leaf springs require fewer components and less post-processing.

While GFRP manufacturing involves more precise mold-based processes, these can be optimized with proper tooling and batch production. The reduction in part count and potential for automation make composite leaf springs a promising alternative for the E-Rickshaw segment.

However, long-term cost benefits such as lower maintenance or extended service life could not be conclusively assessed in this study, as no real-world fatigue or lifecycle testing was performed. These factors remain areas for future investigation.

Conclusion

This study presents a comparative evaluation between traditional EN45 steel multi-leaf springs and Glass Fiber Reinforced Polymer (GFRP) composite mono-leaf springs specifically designed for E-Rickshaws operating in Indian urban conditions.

The analysis reveals that composite leaf springs offer significant advantages in terms of weight reduction, better load distribution, and corrosion resistance. These benefits directly contribute to improved vehicle dynamics and potentially greater energy efficiency—two critical factors for enhancing the performance and operating range of battery-powered rickshaws.

However, this study also highlights the need for further experimental validation under actual service conditions, including fatigue testing, thermal aging, and exposure to environmental factors typical of Indian climates. Such future work will provide more definitive insights into the durability and practical viability of composite leaf springs in real-world applications.

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