Mechanical Behavior of Fiber Glass and Rubber Reinforced Epoxy Composites

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Abstract - Hybrid composite materials are among the most effective options for providing good suspension in wheeled vehicle applications. By reducing the weight of suspension systems, they help lower overall fuel consumption and costs. A common approach is to replace traditional steel components with composite materials. To enhance safety, comfort, and durability, composites have been introduced, thanks to their excellent strength-to-weight ratio, corrosion resistance, and ability to store significant elastic strain. This study investigates the structural properties of a hybrid composite material composed of 95% epoxy, 5% rubber, 5% glass fiber, and 5% hybrid reinforcement of rubber and glass fiber. The hand lay-up method is selected for fabrication due to its advantages over other techniques. To evaluate the performance of the proposed composite leaf spring, mechanical experiments including tensile, impact, and hardness tests are conducted. The results demonstrated that the addition of reinforcing fibers improved tensile strength, impact resistance, and hardness. The best mechanical properties are achieved with the use of hybrid reinforcement.

Key Words: Epoxy, glass fiber, rubber, composite, mechanical properties.

1. INTRODUCTION

A spring is an elastic element that deforms under external loads and returns to its original shape once the load is removed, depending on the magnitude of the applied force. Springs are primarily used to absorb shock and vibration and to store potential energy through deflection during load application. Leaf springs, commonly used in trucks and other vehicles, serve to absorb shock and vibration and can be designed to withstand heavy loads. Enhancing the strength of a leaf spring improves the suspension system, contributing to a smoother ride. However, the failure of a leaf spring can have severe consequences. Compared to helical springs, leaf springs offer the advantage of having their ends aligned along a specific path, allowing them to function both as a spring and a structural component [1-3].

Depending on the vehicle design, leaf springs can be installed in two main configurations. The first is a simply supported leaf spring, where both ends are attached to the vehicle chassis. The second is a cantilever leaf spring, with one end fixed to the vehicle frame and the other end free to move. Steel is a widely used material for manufacturing leaf springs due to its strength and durability. Leaf springs typically feature a slender, arc-shaped profile and a rectangular cross-section. The base of the arc helps determine the position of the axle, while both ends of the spring are connected to the chassis via loops. Serving as a coupling element, the leaf spring secures the axle, making it a critical component in vehicle suspension systems. The primary functions of multi-leaf springs include absorbing shocks, carrying lateral loads, and transmitting braking and driving torque [4-5]. A multi-leaf spring consists of a set of semi-elliptic flat plates or “leaves” that are held together by a central clip and U-bolts. These leaves are of two types: graduated-length leaves and full-length leaves. Graduated leaves vary in length, with shorter ones placed at the top and longer ones at the bottom. The master leaf is the longest and topmost leaf, providing structural integrity. Full-length leaves help sustain transverse shear forces, contributing to the overall load-bearing capability of the spring. Rebound clips are used to hold the leaves in position and prevent lateral movement during operation. The ends of the spring are fixed to the vehicle frame, allowing the spring to be supported by the axle. A flexible linkage, often a shackle, connects the rear end of the spring to the frame, accommodating changes in spring length during compression and rebound. One of the most commonly used types of springs is the semi-elliptical leaf spring. Recently, leaf springs made from hybrid composite materials have gained attention due to their potential advantages. In the longitudinal direction, these materials are selected for their high strength and low elasticity, which makes them suitable for spring applications [6-8].

Failures in conventional steel leaf springs often result from accidents or fatigue, but such failures can be minimized by using progressively failing composite leaf springs. These composite springs are capable of significant weight reduction, which can be further enhanced through optimized design and improved manufacturing techniques. Composite leaf springs can reduce the un-sprung weight of vehicles by 10–20%, contributing to improved ride quality and performance [9].

A critical aspect of spring design is the ability to absorb and store energy, then release it efficiently. The strain energy of the spring material plays a key role in this process. Strain energy can be calculated using standard mechanical formulas, and according to these, materials with lower density and lower Young's modulus tend to exhibit higher specific strain energy. This means that with appropriate material selection, the weight of the leaf spring can be reduced without sacrificing load-bearing capacity or stiffness. While steel has high strength, it is heavier and less elastic compared to composite materials. In the design of composite springs, several architectural constraints must be considered, including von Mises stresses, bending stresses, and deflection limits. Leaf springs play a critical role in absorbing vertical movements and impacts caused by road irregularities. The vibrations induced by these irregularities are absorbed as strain energy, which is then gradually released, contributing to vehicle stability and comfort. Advanced composite materials have proven to be ideal for such applications. By adjusting the elasticity of the composite, it is possible to reduce internal stresses while increasing overall strength a key factor in improving spring performance. As a result, composite leaf springs have become increasingly important when compared to traditional steel springs. Several studies have been conducted to explore the performance of composite leaf springs [10].

Composite leaf spring is fabricated using a combination of three materials via the open molding process, demonstrating the practical feasibility of multi-material composite designs for suspension systems.In one study, a composite leaf spring is fabricated using a three-layer structure: carbon fiber as the first layer, epoxy resin as the second, and pineapple fiber as the third. This configuration demonstrated excellent results in terms of high strength, stiffness, and lightweight properties, attributed to the composite's inherent corrosion resistance and superior strength-to-weight ratio. Further investigations into the replacement of traditional steel leaf springs with carbon fiber-reinforced polymer (CFRP) composites are carried. The study concluded that CFRP springs offered both significant weight reduction and high mechanical strength, which not only improved vehicle efficiency but also contributed to reduced fuel consumption. Finite element analysis is utilized to evaluate the fatigue life and flexural behavior of the composite leaf springs, revealing better performance compared to steel springs. CFRP springs demonstrated higher stiffness, less deformation, and extended fatigue life due to their lower density and superior elastic properties [11-12].

Metallic leaf springs are contribute significantly to the vehicle's static weight, which negatively affects fuel efficiency. Composite materials, with their lightweight and durable characteristics, have been identified as suitable replacements. Following material selection, experimental tests are conducted to validate the mechanical properties and performance of the proposed composite leaf spring designs. The use of glass/epoxy composite materials resulted in a 57.23% reduction in weight compared to metallic leaf springs, along with an 18% decrease in stiffness relative to steel leaf springs. Various composite materials are evaluating their stiffness, deflection, and stress characteristics under identical design parameters. The findings demonstrated that several composite options exhibited superior performance when compared to traditional steel springs. Among the tested materials, Boron/Aluminum composites showed low deflection and stress, coupled with high stiffness, making them favorable choices over other composite variants and focused on lightweight vehicle design using composite leaf springs. The integration of Kevlar fibers into the spring material contributed to a significant reduction in weight, while maintaining the necessary structural strength. Kevlar is found to be the lightest among the tested materials and capable of withstanding high loads with minimal deformation. Based on a static analysis comparing steel and composite materials, Kevlar-based leaf springs are determined to offer the best performance among the tested alternatives [13].

2. MATERIALS AND METHODS

The composite material consists of an epoxy (Cleaver) matrix, reinforced with glass fibers, rubber, and hybrid fibers, with their respective mechanical properties detailed in Tables 1 and 2. The fabrication process is carried out using the hand lay-up molding technique, which allows for precise control over the layering sequence and composite thickness. To ensure optimal performance, the reinforcing fibers are applied sequentially, layer by layer, following a predetermined order. The epoxy resin and hardener are mixed in a 3:1 ratio to achieve proper curing and bonding characteristics.

Epoxy resin is applied to the fiber layers using a brush application method. The first layer consisted of epoxy, followed by layers of glass fibers, rubber fibers, or a hybrid of both, arranged according to the desired weight percentages specified in Table 3. To ensure complete curing of the epoxy, the composite sheets are left at room temperature (27°C) for 24 hours. Subsequently, the sheets are placed in a drying oven at 60°C for 1 hour to eliminate residual stresses and air bubbles formed during the lay-up process. For mechanical testing, a total of 292 specimens are cut from the cured composite sheets in accordance with ASTM standards.

Table 1. Properties of Epoxy

Properties of epoxy	**Value**
Tensile strength	60-80 Mpa
Modulus of elasticity	2.9-3.2 Mpa
Deformation	4-7%
Impact energy	35-50 J

Table 2. Properties of fiber glass

Properties of fiber glass	**Value**
Tensile strength	3400 Mpa
Tensile elongation	2.6%
Modulus of elasticity	76 Mpa
Density	2.65 gr/l

Table 3. Composite sample used

Samples	Weight ratio
A1	Epoxy
A2	Epoxy + 4 layer of fiber glass
A3	Epoxy + 4 layer of rubber
A4	Epoxy + 2 layer of rubber + 2 layer of fiber glass

3. RESULTS AND DISCUSSIONS

3.1 Tensile strength test

The addition of glass fibers and rubber to the epoxy matrix significantly increases the tensile strength of the composite. The measured tensile values are 134 MPa for Sample A4, 42 MPa for Sample A3, and 145 MPa for Sample A2, as presented in Fig - 1. The most notable improvement occurred with hybrid fiber reinforcement, which combines the beneficial properties of both fiber types. Since epoxy resin is inherently porous and possesses low tensile strength, reinforcement with fibers enhances its mechanical performance.

Glass fibers, known for their high ultimate tensile strength and ductility, contribute significantly to the strength and durability of the epoxy matrix. In contrast, increasing the proportion of rubber layers in the composite leads to greater elastic behavior but a reduction in tensile strength, as depicted in Fig - 2.

Various fiber stacking sequences GRGR, GRRG, RGRG, and RGGR are tested, and the GRGR configuration demonstrated the best performance. This improvement is attributed to the configuration's ability to absorb the entire load through the fiberglass layers, as illustrated in Fig - 3.

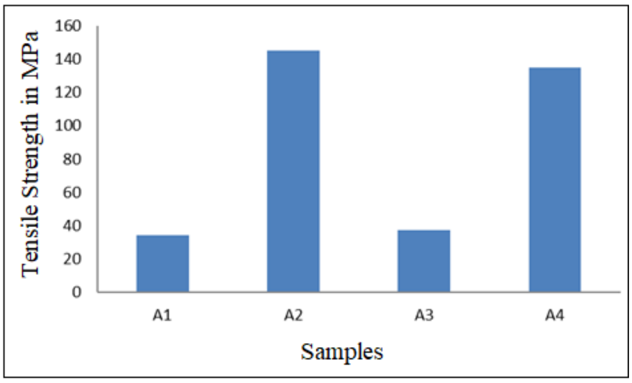

Fig - 1: Composite sample tensile strength

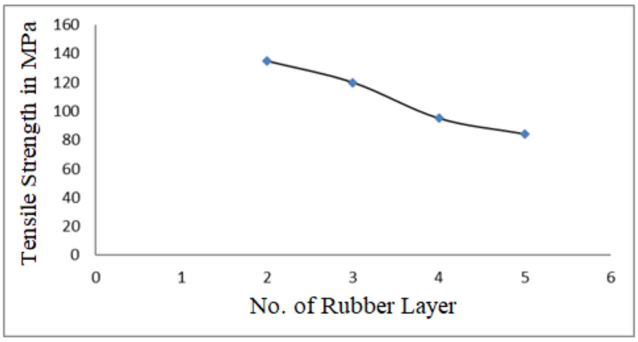

Fig - 2: Composite tensile strength with Rubber layer

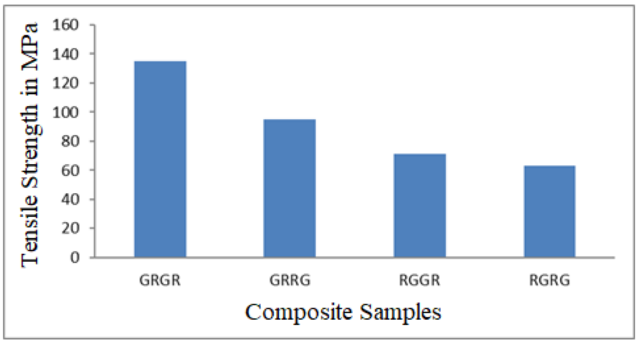

Fig - 3: Composite tensile strength of Fiber Glass with Rubber layer

3.2 Test of Hardness

Fig - 4 illustrates the results of Shore D hardness tests, revealing a noticeable improvement in the hardness of the composite materials. The most significant increase in hardness is observed with the addition of glass fibers, due to their inherent high strength and resistance to deformation.

Samples A2 and A3 exhibited higher hardness values than A1, primarily because of their enhanced strength and improved ability to withstand external loads. The highest hardness value is recorded for Sample A4, which combined both rubber and glass fibers, effectively utilizing the complementary properties of both reinforcement materials.

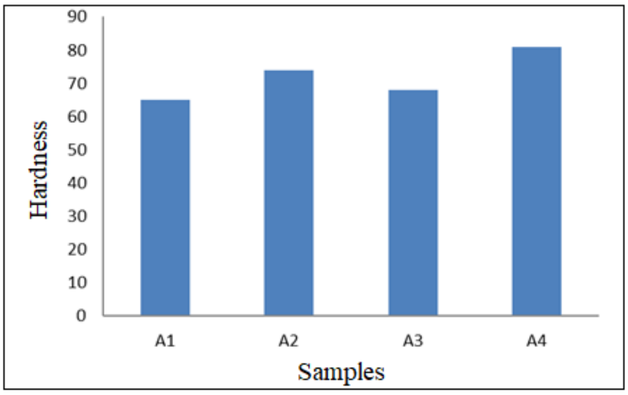

Fig - 4: Composite sample hardness strength

3.3 Impact Test

The impact strength of the composite materials is evaluated using the Charpy impact test, which measures a material's toughness its ability to absorb energy during fracture. According to the results shown in Fig - 5, pure epoxy demonstrated a low impact strength of 13 kJ/m², reflecting its brittle nature and poor resistance to sudden impacts. In contrast, the composite samples A2, A3, and A4 showed significantly improved impact strength values of 139, 26 and 132 kJ/m² respectively. This enhancement is attributed to the presence of reinforcing fibers, which effectively absorb and distribute impact energy, thereby reducing crack propagation and improving the overall toughness of the material.

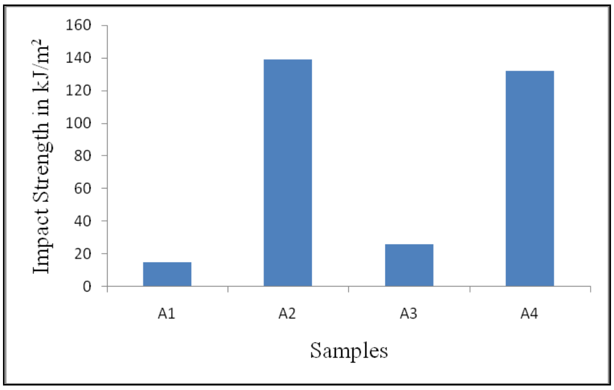

Fig - 5: Composite sample effect energy values

4. CONCLUSION

When the epoxy matrix is reinforced with rubber and glass fibers, both the tensile strength and impact resistance of the material increased due to the high strength and ductility of the reinforcements. Among the tested fibers, glass fiber exhibited the strongest mechanical performance in impact tests. The proposed hybrid composite benefits from the combined properties of glass and rubber fibers glass fibers contribute high tensile strength and rigidity, while rubber adds elasticity and energy absorption. Additionally, all three components of .the composite epoxy, glass fiber, and rubber have lower densities compared to steel, resulting in a significant reduction in overall weight. Researching the mechanical behavior of such hybrid composites supports their potential as lightweight, high-performance materials for various structural and automotive applications.

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