

Mechanical Properties Analysis of Jute/E-Glass Fiber Reinforced Composite for Leaf Spring Application

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Abstract

This study evaluates the mechanical properties of jute, E-glass, and hybrid fiber-reinforced composites to identify a suitable replacement for conventional metal leaf springs in automotive applications. Tensile, flexural, and impact tests were conducted in accordance with ASTM standards on three composites made from woven jute and woven E-glass fibers at a 70:30 volume fraction. Among all samples, the E-glass composite exhibited the highest mechanical performance, achieving tensile and flexural strengths of 404.84 MPa and 229.06 MPa, respectively, along with the maximum impact strength of 73.42 MPa. These results indicate that E-glass fiber composites offer superior strength and energy absorption characteristics in contrast to jute and hybrid composites, making them a strong candidate for lightweight automotive suspension components. To further assess the mechanical properties, a numerical analysis was carried out in ANSYS using the same E-glass-epoxy incorporating 70:30 volume fraction. The simulation aimed to evaluate stress reduction, deformation behavior, and strain-energy absorption relative to a conventional steel leaf spring. The composite leaf spring demonstrated a 4.58% reduction in stress under identical loading conditions, an 89.36% increase in deformation capability, and an 89.86% improvement in strain-energy absorption. Additionally, the composite design achieved a significant weight reduction of 74.5%. Overall, the findings highlight the potential of E-glass fiber-reinforced composites as an efficient, lightweight alternative to traditional steel leaf springs, offering enhanced mechanical performance and improved ride quality.

Keywords

Fiber-reinforced composite materials, E-glass fiber, Jute fiber, Leaf spring, and Flexural strength.

1. Introduction

It is well known that steel leaf spring failures are typically disastrous. It is crucial to lessen accidents and eventually replace steel leaf springs with composite materials made of FRP (fiber reinforced polymer). Another consideration is to lighten the vehicle while maintaining the necessary strength, which is made possible by FRP composite materials. FRP material has superior fatigue strength, meaning that it can withstand repeated load without breaking. Finally, FRP is highly resistant to both corrosion and wear, meaning that it can last longer than traditional materials. Despite the advantages of using traditional leaf springs, there are some major disadvantages associated with their generation of large stress, which limits their usefulness in high-strength applications. Other advantages of composite leaf spring over the conventional leaf spring includes high strength to weight ratio, high impact resistance, better fatigue resistance, better fatigue resistance, good thermal conductivity etc.

1.1 Objectives

- To fabricate jute, e-glass, jute/e-glass hybrid composite.
- To test the tensile properties of the composite.
- To test the flexural properties of the composite.
- To compare energy absorption of the composite.
- To compare conventional and above tested better fiber-based composite leaf spring numerically.

2. Literature Review

The use of fiber-reinforced composites has increased in recent years due to their unique mechanical properties such as high strength-to-weight ratio, improved stiffness, and enhanced resistance to deformation. Jute fiber is a widely used natural fiber reinforcement in composites due to its low cost, renewability, and biodegradability. E-glass fibers are commonly used as reinforcement in composite materials due to their high tensile strength and low cost. Numerous studies are being conducted on composite materials, particularly natural fiber reinforced polymer composites, as well as their characteristics and qualities under certain environments and production processes.

Kalaprasad and Sabu Thomas have studied the mechanical properties of sisal-glass fiber reinforced LDPE matrix composites with a focus on the effects of fiber orientation on the composite's mechanical performance. Their study showed that the longitudinally oriented fibers exhibit better mechanical properties than randomly oriented fibers. This finding is in line with previous studies on fiber-reinforced composites, which have shown that the alignment of fibers with the applied direction of stress significantly affects the mechanical properties of the composite (Shirke & Shelke, 2022).

M. Ramesh and colleagues conducted a study on the production and assessment of properties of composites reinforced with banana, hemp, and glass fibers. The main objectives of this study were to develop composites using banana, hemp, and glass fibers and to determine their mechanical characteristics, such as tensile strength, flexural strength, and impact strength. The composite was fabricated manually, and a universal testing machine (UTM) was used for mechanical property analysis (Bhoopathi et al., 2014). M. R. Hossain et al. (Hossain et al., 2013) experimented on jute fiber at a constant volume fraction (25%) with different sticking orientation such as (0/0/0/0), 0/90°/90°/0 and 0/+45°/-45°/0. They observed that (0/0/0/0) and 0/+45°/-45°/0 provide better tensile strength in both longitudinal and transverse direction compared to 0/90°/90°/0. But in 0/90°/90°/0 tensile strength are near about equal for longitudinal and transverse direction. Sandeep et al. (Sandeep et al., 2014) worked with glass/epoxy composite and observed that 0/90° have greater flexural strength rather than 0/45°. Prashanth Banakar et al. (Banakar et al., 2012) evaluated the impact of thickness and fiber orientation on glass/epoxy resin composite. They took ±30°, ±45°, ±90° orientation for 2mm and 3 mm thickness individually. After tensile test it is observed that tensile strength decreases with the increase of thickness and 30° orientation provide highest tensile strength.

Over the past few years, automobile manufacturers have been focused on weight reduction to save energy and protect natural resources. One way to do this is by using better materials and designing cars more efficiently. The suspension leaf spring can play a role in weight reduction in automobiles. There are several reasons why fiber-reinforced plastic (FRP) has become a popular choice for replacing steel springs in products such as cars and aircraft. First, the FRP material has a much higher strength-to-weight ratio, meaning that it can withstand greater amounts of fatigue and corrosion. Second, the FRP material has superior fatigue strength, meaning that it can withstand repeated use without breaking. Finally, FRP is highly resistant to both corrosion and wear, meaning that it can last longer than traditional materials. Materials used to make leaves are replaced with composite materials, which are known as composite leaf springs. The invention of composite materials has made it possible to reduce the weight and the stress that leaf springs generate during their operation (D'Silva et al., 2014). When a spring is made of FRP, such as E-Glass/Epoxy, the weight of the spring can reduce by 60-70%. This can lead to a reduction in the weight of the unsprung. The unsprung elements of the car include the wheel assembly, axles, and part of the weight of the suspension spring and shock absorbers. Reducing the unsprung weight could improve the vehicle's ride quality and fuel efficiency. Therefore, the use of composite leaf springs results in both weight reduction and improved riding qualities (Wang et al., 2013).

Leaf springs are one of the simplest types of springs that are commonly used in wheeled vehicle suspension elements that are often found in areas where a simple, lightweight design is desired, such as in the suspension of a car (Jancirani & Assarudeen, 2015). Spring steel or other robust components are thin, long, and flat. Bendable. Simple and practical, the leaf spring has been used for millennia. Cart springs, also known as semi-elliptical springs, are short, rectangular spring steel components shaped like an arc. It can apply moderate pressure in a certain direction (Suresh et al., n.d.).

Leaf springs store energy from vibrations and impacts. Energy is released gradually. Axle springs. Vehicle and occupant weight compress the leaf spring. A leaf spring can operate as a structural part and an energy-absorbing device, making the ride more comfortable for passengers(Jenarathanan et al., 2018).

S. Mehul et al. compared standard leaf springs SUP 9 with composite leaf springs composed of carbon/epoxy and Unidirectional graphite/epoxy laminate. The main conclusion of this study is that under the same load conditions, the weight of the multi-leaf spring is 79.617% lighter, while the same single-leaf spring is 90.090% lighter. The standard spring material has been replaced by a composite spring material (Sorathiya et al., 2014).

I. Rajendran and S. Vijayarangan provided a solution technique that optimizes the design of a leaf spring using genetic algorithms. This method reduced the vehicle's unsprung mass by working with the solution set's coding, employing a population of solutions, and employing probabilistic transition rules. It was discovered that ordinary materials for leaf springs can reduce weight by up to 8%, composite materials can reduce weight by up to 23.4 percent, and when a multi-leaf spring system is replaced with a composite mono leaf, it can reduce weight by up to 75.6 percent by optimizing its design(Rajendran & Vijayarangan, 2001). Krishan and Aggarwal followed a finite element approach for design and stress-deflection analysis of a multi leaf spring using CAE tools (i.e., CATIA, ANSYS). They found that when the leaf spring is fully loaded, a variation of 0.632 % in deflection is observed between the experimental and FEA result, and same in case of half load, which validates the model and analysis. Bending stress in both cases is also close to the experimental results. The maximum value of equivalent stresses is below the Yield Stress of the material that leads to safe design from failure (Rajendran & Vijayarangan, 2001).

Mayur D. Teli, Umesh S. Chavan, Haribhau G. Phakatkar design analysis and did experimental performance test for electric vehicle's composite multi-leaf spring using Glass Fiber Reinforced Plastic (GFRP). Constructional arrangement was simple conventional semi elliptical leaf spring. In his study the data was taken for the traditional semi elliptical leaf spring of TATA Sumo Gold passenger car vehicle model. Experimental and finite element analysis were compared for validation and observed that difference in values for deflection 3.93%, for stiffness 4.06%, for energy absorbed 3.94% and for natural frequency is 5.25%, which are satisfactory values. 8. Weight difference between EN 46 leaf spring and GFRP leaf spring is 67.70% (Teli et al., 2019).

3. Materials and Methodology

3.1 Description About Used Materials

Jute-Glass fiber composites were created using a variety of materials, including natural woven jute fiber, woven E-glass fiber as a reinforcing agent, and epoxy resin and hardener as a binder or matrix material. Another use for grease is as a release agent.

3.1.1 Jute Fiber

Jute is known as the "Golden fiber" due to its significance and beautiful golden color. It is the second most produced and used fiber after cotton, and it is highly beneficial for the environment. Jute production is easy and yields high profits on each piece of land, and it requires fewer pesticides and fertilizers compared to cotton. Jute is a blast fiber like flax and hemp, and it grows annually in the Ganges Delta of Bangladesh, yielding more than 80%. The Kew Royal Botanic Gardens categorizes jute under the Tiliaceae family, while it has been previously associated with cotton in the Malvaceae or Sparrmanniaceae family.

Table 1. Chemical composition of jute fiber (Park et al., 2014)

Components	Percentage
Cellulose	65.2
Hemi-cellulose	22.2
Lignin	10.8
Water soluble	1.5
Fat and wax	.3

3.1.2 Glass Fiber

Fiberglass is another name for glass fiber. It is a substance made from extremely tiny glass filaments. Fiberglass is a strong, remarkably robust, lightweight material. The material is typically far less delicate, and the raw materials are significantly less expensive, even though its quality qualities are somewhat lower than those of carbon fiber and it is less toughened. When compared to metals, their mass quality and weight characteristics are also quite good, and it is very likely that it can be easily molded using shaping methods. As a result, glass filaments are used as a strengthening operator for some polymer products. Different varieties of glass fiber, such as roving, woven, unidirectional, bidirectional, etc., are utilized for various purposes.

Table 2. Chemical composition of E-glass fiber (Das K. et al., 2009)

Constituent	Quantity in %
SiO ₂	55.2
Al ₂ O ₃	14.8
B ₂ O ₃	7.3
MgO	3.3
CaO	18.7
K ₂ O	0.2
Na ₂ O	0.2
Fe ₂ O ₃	0.2
Fe ₂	0.1

3.1.3 Matrix Material

In hybrid composites, extra glue or adhering components are frequently utilized to bind the reinforcing or strengthening material; these are referred to as matrix materials. One of the most prevalent matrix phases between reinforcing material, which serves as a continuous medium, is epoxy resin. A resin and an extra hardener make up epoxy resin. Chemical reactions between the hardener and resin cause the liquid phase to solidify.

3.1.4 Releasing Agent (Grease)

Various release agents are utilized while fabricating by hand. When compared to other release agents, grease functions better. It is in a semi-solid state. Because composite plates are removed from the mold without any touch with the polythene after curing times, polythene is applied on the mold plate using grease during fabrication.

Table 3. Reinforcing and matrix material properties

Type	Thickness (mm)	Specific gravity	Poison Ratio	Density (Kg/m ³)	Young Modulus (GPa)
Jute fiber mat	1.5	1.48-1.50	0.38	1300	26-30
Glass fiber mat	0.55	2.56	0.21	2540	72
Epoxy resin	-	1.12	0.4	1150-1200	2.68
Hardener	-	1.02	-	1200	-

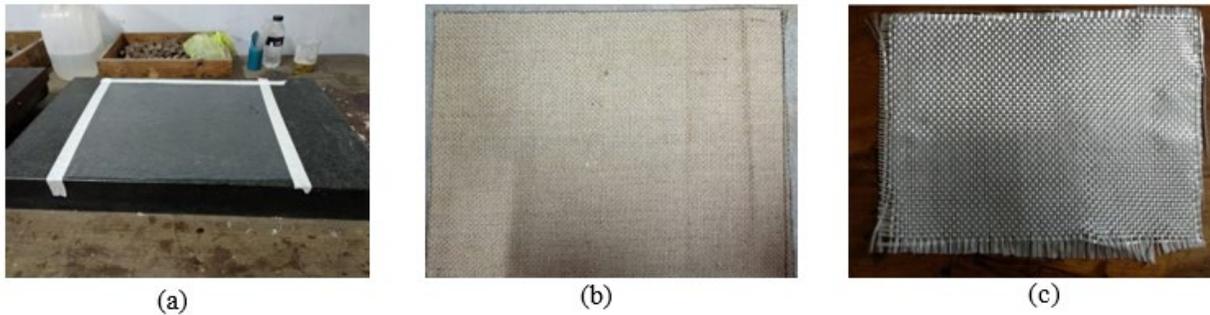


Figure 1. (a) prepared mold for lay-up process, (b) 30cm x 30cm Jute Fiber Mat (c) 30cm x 30cm E-Glass Fiber Mat

3.2 Proper Mixing of Epoxy Resin

As a matrix phase, Ly 556 resin and HY951 hardener were utilized. Prior to construction, multiple ratios of resin and hardener (2:1, 3:1, 10:1) were mixed to determine which sorts of mixture would be best for transparency. 3:1 ratio offers crystal clear transparency. Therefore, for all forms of composite, 3:1 ratio was employed.

3.3 Lay-up Technique

To prevent any movement, transparent polythene was first placed on a block (mold). It was secured to the block with masking tape. Then a hand roller was used to evenly disperse the resin-hardener mixture that had been placed onto the polythene. Fiber mats are then successively positioned and burnished with epoxy glue. Making ensuring that all of the fibers were saturated with resin and that there were no dry spots was of utmost importance. The entire composite was covered in polythene to prevent air from passing through once all layers had been saturated with resin. Thus, the possibility of void fraction was eliminated.

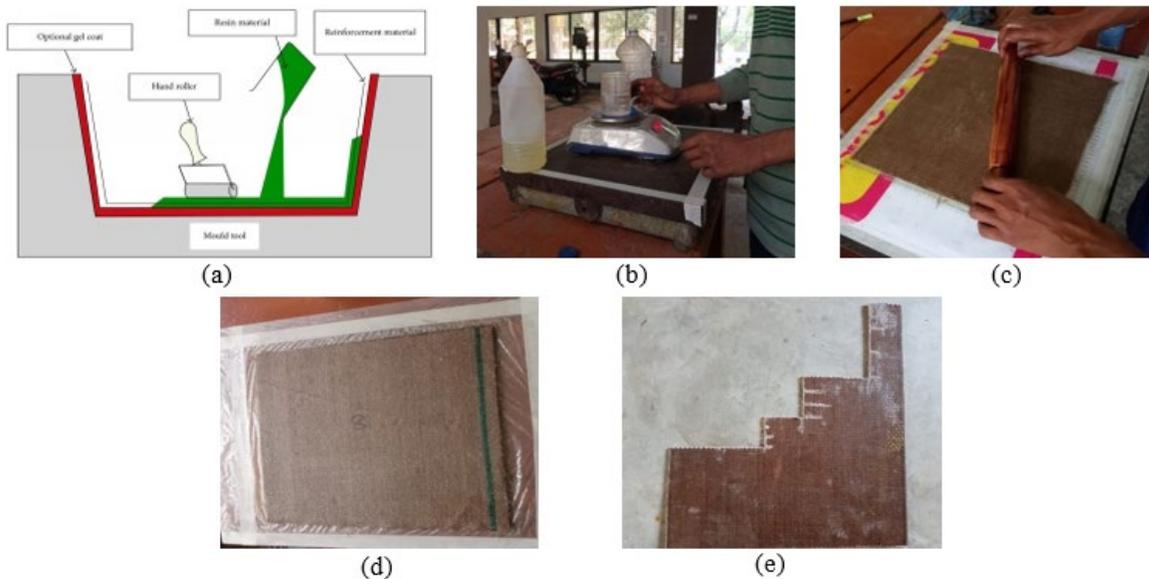


Figure 2. (a) - (e) show processes incorporated from Epoxy Resin mix to Lay-up Technique to fabricate FRP Composite layers.

Table 4. Volume fraction control of all composites

Type	Thickness (mm)	Specific gravity	Poisson Ratio	Density (Kg/m ³)	Young Modulus (GPa)
Jute fiber mat	1.5	1.48-1.50	0.38	1300	26-30
Glass fiber mat	0.55	2.56	0.21	2540	72
Epoxy resin	-	1.12	0.4	1150-1200	2.68
Hardener	-	1.02	-	1200	-

4. Experimental Procedures

4.1 Tensile Test

This is the most essential mechanical properties of material. According to standard for composite material tensile test ASTM D3039 was followed and test with 3 specimens for each sample. The work piece was loaded axially while clamped in the testing machine's jaws. Before loading for strain computation, the composite material specification determined the gauge length. The fiber and matrix slowly connected under the force, and the composite fractured after the required load. On a computer screen, ultimate force is the material's breaking load.

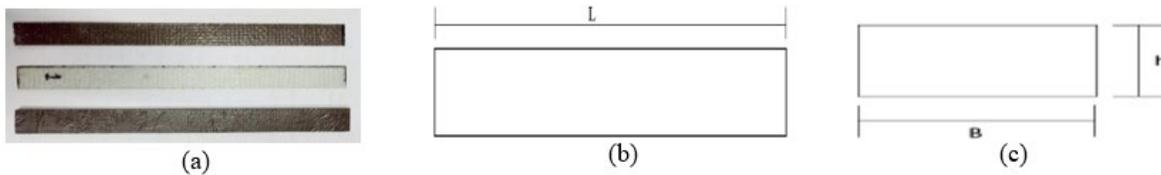


Figure 3. (a) - (b) Schematic size of tensile specimen

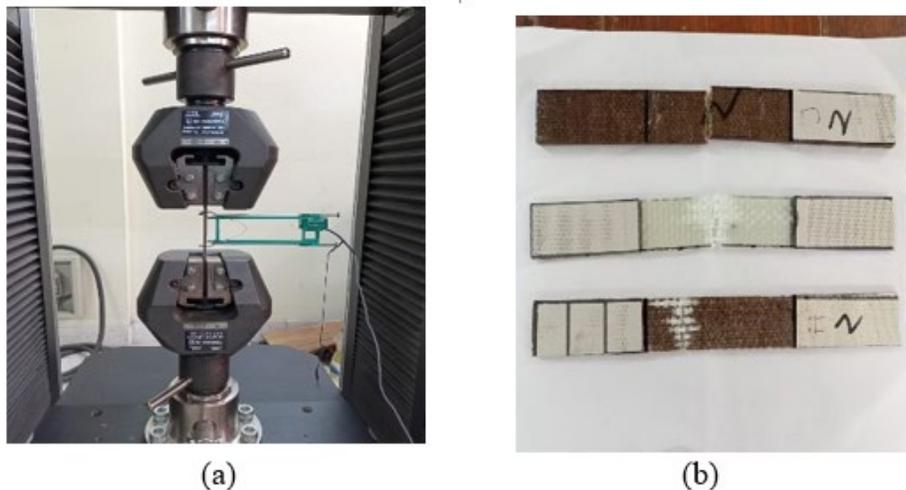


Figure 4. (a) Tensile test specimen on UTM, and (b) Specimen after break

Table 5. Tensile test specimen details

Specimen		Length (mm)	Width (mm)	Thickness(mm)	Area (mm ²)
Jute fiber composite	Sample 1	250	27.15	4.90	133.03
	Sample 2	250	27.01	4.97	134.23
	Sample 3	250	26.93	4.95	133.30
Glass fiber composite	Sample 1	250	25.94	1.42	36.83
	Sample 2	250	26.36	1.35	35.58
	Sample 3	250	26.05	1.42	36.99
Jute-Glass hybrid composite	Sample 1	250	24.91	2.97	73.98
	Sample 2	250	25.80	3.02	77.91
	Sample 3	250	25.50	3.00	76.5

Table 6. Ultimate tensile strength of specimen

Specimens		Ultimate Tensile Strength, σ (N/mm ²)	Strain at break (%)	Young Modulus (GPa)
Jute fiber composite	Sample 1	45.64	12.82	8.34
	Sample 2	40.57	10.77	8.52
	Sample 3	45.39	14.05	8.09
Glass fiber composite	Sample 1	398.43	13.69	48.20
	Sample 2	431.22	14.59	51.02
	Sample 3	384.87	13.31	51.16
Jute-Glass hybrid composite	Sample 1	95.92	10.55	17.59
	Sample 2	83.26	9.40	15.61
	Sample 3	101.85	11.51	15.14

4.2 Flexural Strength Test

For the flexural test specimens were set up according to the ASTM D790 (Annu B., 2007) standards. Each specimen was 160 mm by 13 mm. Each type examined three specimens. The most common composite material flexural test is the 3-point test. The crosshead position predicts specimen diversion. The test specimen is placed in the universal testing machine and forced to break.

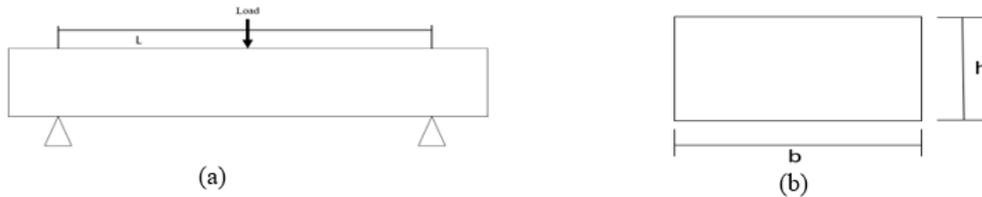


Figure 5. (a) - (b) Schematic diagram of Flexural strength test specimen

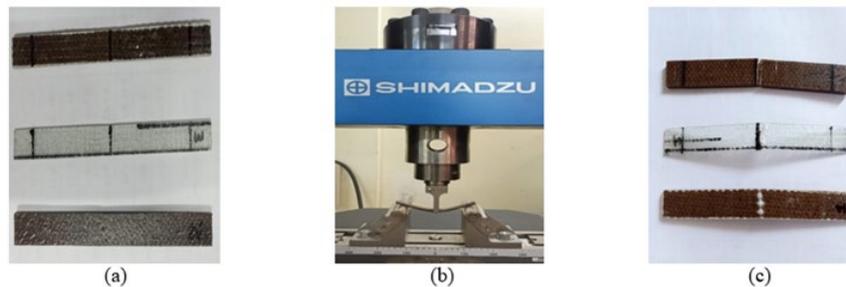


Figure 6. (a) Flexural test specimen, (b) Specimen on loading condition, and (c) Specimen after break

Table 7. Flexural test specimen details

Specimens		Span Length, L (mm)	Width, b (mm)	Thickness, t (mm)
Jute fiber composite	Sample 1	128	15.22	4.54
	Sample 2	128	15.20	4.47
	Sample 3	128	14.6	4.36
Glass fiber composite	Sample 1	128	13.99	1.41
	Sample 2	128	13.60	1.41
	Sample 3	128	13.93	1.42
Jute-Glass hybrid composite	Sample 1	128	14.55	3.07
	Sample 2	128	14.72	3.08
	Sample 3	128	14.91	3.03

Table 8. Ultimate flexural strength of different composites

Specimens		Ultimate Flexural Strength, σ (N/mm ²)	Strain at break (%)	Young Modulus (GPa)
Jute fiber composite	Sample 1	73.32	3.4273	20.79
	Sample 2	70.85	3.6667	18.56
	Sample 3	61.24	3.2295	14.90
Glass fiber composite	Sample 1	237.76	1.30	132.51
	Sample 2	217.03	1.26	111.37
	Sample 3	232.38	1.37	138.48
Jute-Glass hybrid composite	Sample 1	98.54	1.36	76.38
	Sample 2	96.66	1.34	74.50
	Sample 3	93.88	1.33	71.97

4.3 Impact Strength Test

Impact strength test is the extent of the proportion of essentiality that a material can hold before breaking under a high pace of distorting. For, impact test ASTM A370 was followed. To evaluate the impact strength 3 specimens of per sample were tested and then average the value to get appropriate impact strength. The pendulum weight of Charpy impact tester was 20 kg.

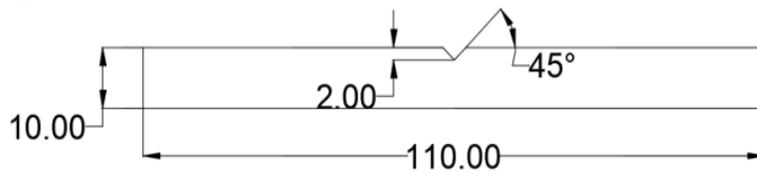


Figure 7. Schematic diagram of impact test

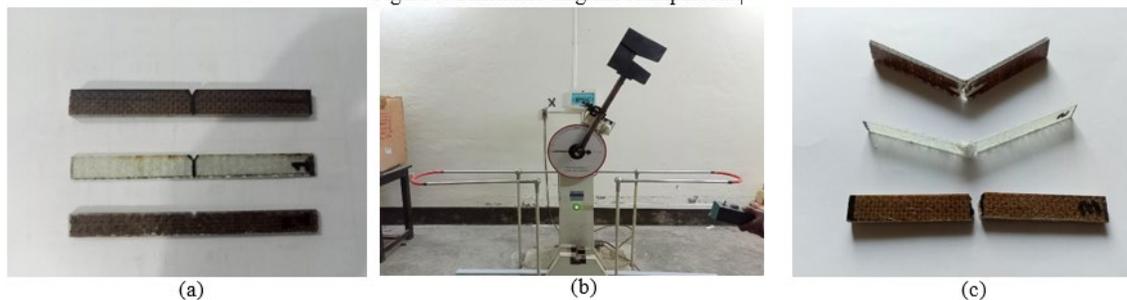


Figure 8. (a) V-notch cutting specimen, (b) Specimen on impact machine, and (c) Specimen after breakage

Table 9. Specimen details for impact test

Specimen		Length (mm)	Width (mm)	Thickness (mm)	Area (mm ²) b*h	Area (cm ²)
Jute fiber composite	Sample 1	111.85	10.14	4.72	47.86	.4786
	Sample 2	111.54	10.25	4.82	49.40	.494
	Sample 3	112.36	10.03	4.82	48.34	.4834
Glass fiber composite	Sample 1	112.44	9.02	1.42	12.80	.128
	Sample 2	111.89	8.76	1.40	12.264	.1264
	Sample 3	110.90	9.08	1.30	11.80	.1180
Jute-Glass hybrid composite	Sample 1	111.22	10.43	3.10	32.33	.3233
	Sample 2	110.21	9.80	2.95	31.86	.2891
	Sample 3	110.92	11	3.025	33.275	.3327

Table 10. Impact strength of different composites specimens

Specimen		Initial height h ₁ , m	Impact height h ₂ , m	Height difference (h ₁ -h ₂), m	Impact Energy J	Impact Strength J/cm ²	Average Impact Strength J/cm ²
Jute fiber composite	Sample 1	1.42	1.355	.065	12.75	26.64	23.12±3.13
	Sample 2	1.42	1.368	.052	10.20	20.64	
	Sample 3	1.42	1.366	.054	10.68	22.09	
Glass fiber composite	Sample 1	1.42	1.373	.0464	9.10	71.09	73.42±2.03
	Sample 2	1.42	1.372	.0479	9.40	74.36	
	Sample 3	1.42	1.375	.045	8.829	74.82	
Jute-Glass hybrid composite	Sample 1	1.42	1.365	.055	10.79	33.37	37.54±3.97
	Sample 2	1.42	1.372	.056	10.98	37.97	
	Sample 3	1.42	1.35	.07	13.73	41.28	

5. Numerical Procedures

5.1 Specification and Geometry of Leaf Spring

The 3D geometry of the model was created using SolidWorks. The model consists of seven parts, such as a master leaf, a full graduated leaf, and five graduated leaves. The structure is made from the dimensions shown in Table 12. Finally, this part of the geometry is imported into Ansys 2022 R2 for numerical analysis. The leaf spring is used in the TATA SUMO vehicle, for Rear Suspension, specimens are given below(Teli et al., 2019).

Table 11. Impact strength of different composites specimens

Remarks	Value
Model	Tata Sumo Gold
Engine	2956 cc
Max Power	62.52 Kw,85ps@30000 rpm
Max Torque	250 Nm @ 1000-2000 rpm
Suspension	Leaf spring and antiroll bar
Kerb weight	1940 Kg
Gross Weight	2790 Kg

Table 12. Impact strength of different composites specimens

Parameter	Value	Unit	Notion
Total length of leaf	980	mm	2L
No. of full-length leaves	2	unit	n_f
No. of graduated leaves	5	unit	n_g
Total no of Leaf	7	unit	n
Thickness of leaf	15	mm	t
Width of leaf	90	mm	B
Inside diameter of eye	18	mm	d
Distance between U bolt	110	mm	l
Camber of leaf spring	87	mm	Y

Length of span or overall length of the spring, $2L_1=980$ mm

Effective length of the spring, $2L = 2L_1 - l = 980 - 110 = 870$ mm

Length of smallest leaf = Effective length/ $n-1$ - Ineffective length

Length of next leaf or nth leaf = Effective length/ $n-1 \times n$ + Ineffective length [30].

Camber of leaf spring = $.089 \times$ span length = 87

Relation between radius of curvature (R) and the camber (y), $R = (L_1)^2 / 2y = 1336$ mm

length of the smallest leaf = $870 / 7 - 1 + 110 = 255$ mm

length of the 2nd leaf = $870 / 7 - 1 \times 2 + 110 = 400$ mm

length of the 3rd leaf = $870 / 7 - 1 \times 3 + 110 = 545$ mm

length of the 4th leaf = $870 / 7 - 1 \times 4 + 110 = 690$ mm

length of the 5th leaf = $870 / 7 - 1 \times 5 + 110 = 835$ mm

length of the 6th leaf = $870 / 7 - 1 \times 6 + 110 = 980$ mm

length of the master leaf = length of 6th leaf = $870 / 7 - 1 \times 6 + 110 = 980$ mm

As the vehicle has four wheels, each package of leaf spring accounts for a quarter of the total weight. So,

$F = 2790 \times 9.8 \times 2/4 = 13670$ N.

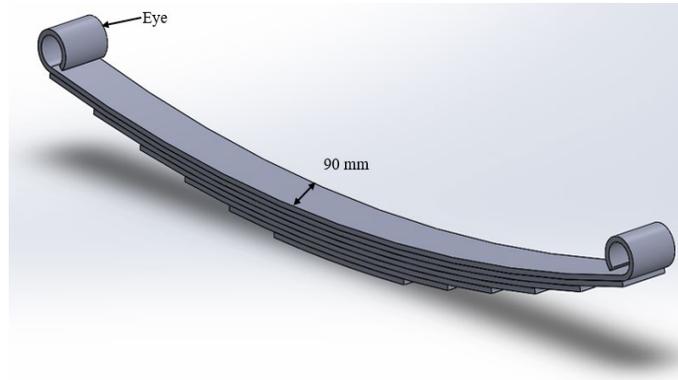


Figure 9. Leaf spring isometric view

5.2 Meshing Geometry

The whole model was meshed, and the total number of elements was 131256. The meshing of the leaf spring is shown in Figure 10(a) – (b).

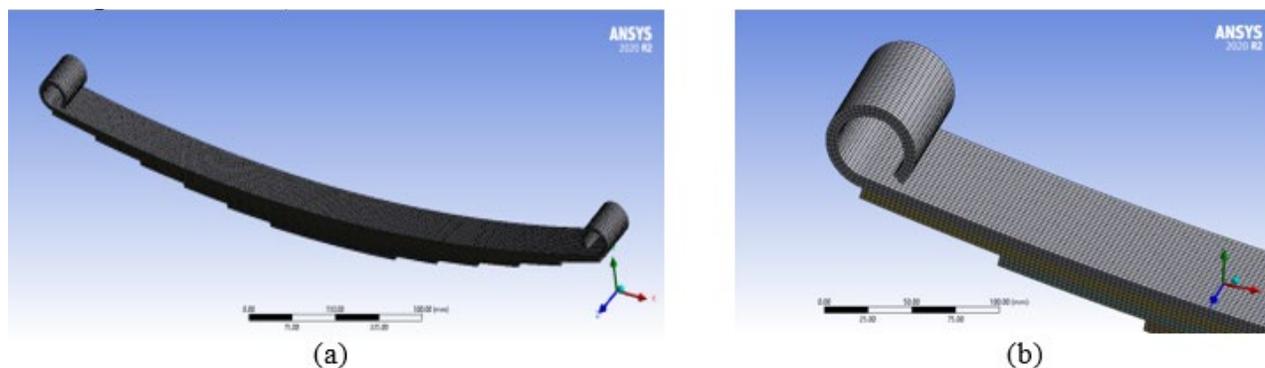


Figure 10. (a) Meshing of the model, (b) Magnified view of mesh

5.3 Boundary Conditions and Loading

The precision of the analysis results relies heavily on the boundary conditions being described accurately. Two boundary conditions were placed at the eyes of both traditional and composite leaf springs. The assembly of the ends is meant to evoke the shape of an eye. In this study, we assume that the leaf spring's eye is stationary and that a 13670 N upward y-axis pressure is exerted on the bottom graduated leaf plate. This weight represented the worst-case situation for the leaf spring when it was in service. To model the limitations imposed by the leaf spring's connection to the chassis, a fixed boundary condition was placed at the eye of the leaf spring.

5.5 Mesh Sensitivity

For a more accurate outcome, mesh sensitivity is assessed. Figure 11 displays a graph of von Mises stress as a function of the number of elements. According to the graph, von Mises stress grows quickly from element 3857 to number 30670, then it stays the same from element 49320 to number 131256. It appears to be nearly constant after element 131256.

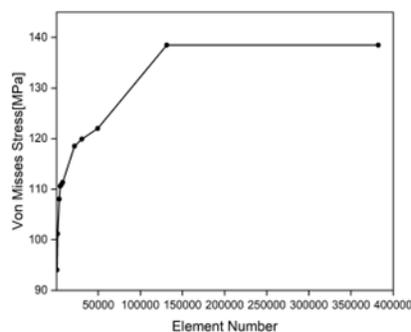


Figure 11. Mesh sensitivity analysis

5.6 Validation of Present Work

Car leaf springs have a semi-elliptical form with a center load of $2P$, both of which can be modeled by a double cantilever. The plate's triangular shape can be achieved by first cutting the leaves in half along their longitudinal axis and then reassembling the halves. The maximum bending stress is given by (R. Ghosh et al., 2016) [31],

$$\sigma(\max) = 6.P.L / n.b.t^2$$

From the equation of maximum bending stress and based on above design specifications, the analytical calculation is carried out for the maximum load acting on the leaf spring of 13670 N.

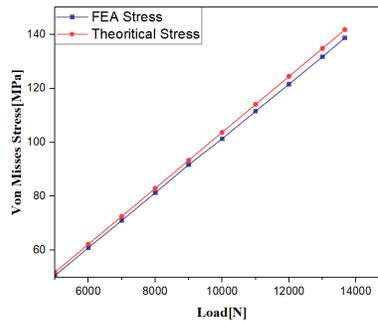


Figure 12. Comparison of present work result with theoretically obtained result for induced stress against applied load

6. Numerical Procedures

6.1 Tensile Test

The tensile test is performed over three samples of each composite. To calculate ultimate stress, the specimen's cross-sectional area is divided by the ultimate force. The gauge length was 50mm and at a crosshead speed of 10mm/ min of stroke was used to test the whole specimen while testing on UTM. Thus, the Load vs Displacement in figure and Stress vs Strain curve (in Figure. 13(a)) is plotted below from obtained testing data. With a maximum load of 15345.4 N, the E-glass composite sample easily outperforms the other two samples (the Hybrid composite sample has a maximum load of 7791.99 N, and the Jute sample reaches its limit at a lower value of 6051.95 N). This data shows that the E-glass composite outperforms the other two samples in terms of strength. Displacement values for the three samples do not, however, trend in the same direction as the maximum load values. The Jute sample has the smallest displacement (7.02 mm), followed by the E-glass composite sample (7.29 mm), and finally by the Hybrid composite sample (5.74 mm). As a result, it can be concluded that the Jute composite is the stiffest of the three. The maximum load and displacement shown by the Hybrid composite sample are intermediate values, showing that it shares characteristics of both Jute and E-glass composite.

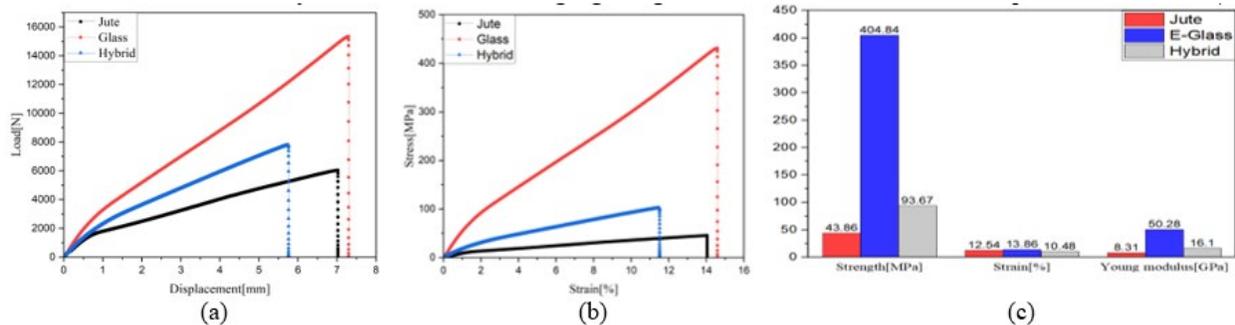


Figure 13. (a) Tensile test load vs displacement curve, (b) Tensile test stress vs strain curve, and (c) Tensile test value comparison of all composites

According to Figure 13(b), the stress vs strain curves the maximum stress value for the E-glass composite sample (431.22 MPa) is the highest among the three samples, followed by the Hybrid composite sample (101.85 MPa), and then the Jute sample (45.39 MPa). This indicates that the E-glass composite is the strongest among the three samples. The strain value for the E-glass composite sample (14.59) is the highest among the three samples, followed by the Hybrid composite sample (11.51), and then the Jute sample (10.77). This indicates that the E-glass composite is the most ductile among the three samples. The E-glass composite has the highest strength and the highest ductility among the three samples, making it a good candidate for structural applications that require both strength and flexibility.

Based on Figure 13(c), the three different composite materials (jute, woven E-glass, and hybrid) have significantly different mechanical properties. In terms of strength, the E-glass composite has the highest strength of 404.84 MPa,

followed by the hybrid composite at 93.67 MPa, and then the jute composite at 43.86 MPa. This indicates that the E-glass composite is the strongest material of the three, while the jute composite is the weakest. In terms of stiffness, the E-glass composite also has the highest tensile Young's modulus of 50.28 GPa, followed by the hybrid composite at 16.1 GPa, and then the jute composite at 8.31 GPa. This indicates that the E-glass composite is the stiffest material of the three, while the jute composite is the most flexible. The hybrid composite appears to be an intermediate between the jute and E-glass composites in terms of both strength and stiffness. In terms of elongation, the E-glass composite has the high strain of 13.86, followed by the jute composite's strain 12.54, and then hybrid composite strain is 10.48. Tensile test is fiber domain-based property. The strain at break of the Hybrid composite sample is lower than that of the Jute composite sample, which may seem counterintuitive since the Jute composite is less strong than the Hybrid composite. In the case of a Hybrid composite, the material properties of both the Jute and E-glass fibers may influence the strain at break. E-glass fibers are stiffer and more brittle than Jute fibers, which means they are more prone to fracture under tensile loading. Another factor that can influence the strain at break of a Hybrid composite is the distribution of the Jute and E-glass fibers within the matrix. If the fibers are not evenly distributed or if there are defects in the composite structure, this can cause stress concentrations and premature failure, which can reduce the strain at break. The E-glass composite is made of high-strength glass fibers having 55.2% of SiO₂ that provide excellent mechanical properties. The jute composite, on the other hand, is made of natural fibers that are typically not as strong as synthetic fibers like glass fibers. The hybrid composite combines both natural and synthetic fibers, which can provide a balance between strength and cost.

6.2 Flexural Test

The three-point flexural test is performed over three samples of each composite in Universal testing machine. The span length of each specimen was 128mm as per ASTM 790 standard and at a crosshead speed of 1mm/ min of stroke was used to test the whole specimen. Thus, the Load vs Displacement in Figure 14(a), and Stress vs Strain curve in Figure 14(b) is plotted below from obtained testing data. The maximum load for the E-glass composite sample (119.805 N) is the highest among the three samples, followed by the Hybrid composite sample (70.302 N), and then the Jute sample (30.564 N). This indicates that the E-glass composite is stronger than the other two composite samples.

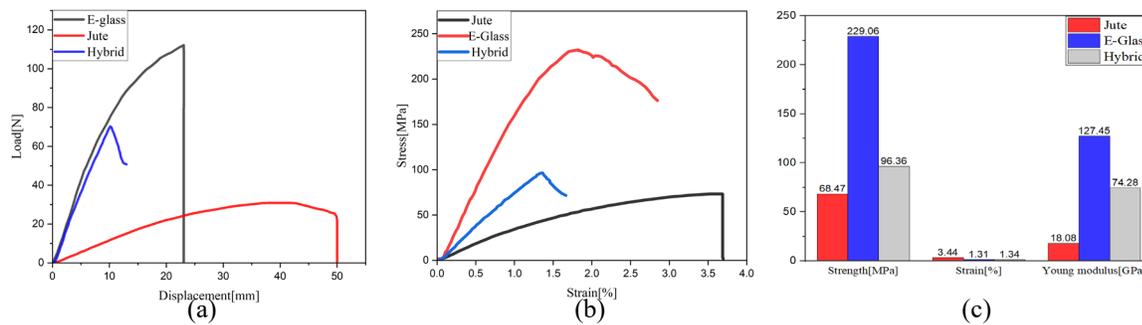


Figure 14. (a) Flexural test load vs displacement curve, (b) Flexural test stress vs strain curve, and (c) Flexural test value comparison of all composites

From the curves in Figure 14(b), we can see that E-glass has the highest maximum stress value of 232.38 MPa, followed by Hybrid composite at 96.66 MPa and Jute at 73.32 MPa. However, it's important to note that E-glass has a much lower strain value at 1.37, indicating that it is more brittle than the other two materials. On the other hand, Jute has the highest strain value at 3.42, indicating that it is more ductile than the other two materials. The Hybrid composite has a moderate maximum stress value and strain value, indicating that it may have a good balance of strength and ductility.

The data shown Figure 14(c) depicts the strength, strain, and flexural modulus of three composite materials: jute, glass, and hybrid. Strength refers to the ability of a material to withstand an applied force before breaking. Jute composite has the lowest strength among the three materials, with a value of 68.47 MPa. Glass has the highest strength with 229.06 MPa. This means that glass is better suited for applications that require high strength, such as structural elements in buildings, windscreens in cars, and automobile leaf springs. Strain is a measure of how much a material deforms under a load. Jute has the highest strain value among the three materials, with a value of 3.44 mm. This means that jute is more flexible and deforms more easily under stress compared to glass and hybrid materials. Jute fibers are natural fibers with relatively low stiffness and high elongation at break, which means they can deform more before

breaking. Glass fibers, on the other hand, are synthetic fibers with high stiffness and low elongation at break, which means they are less likely to deform significantly before reaching their breaking point. Flexural modulus, also known as the bend modulus, is a measure of a material's stiffness. A material with a high flexural modulus is more rigid and less likely to deform under a load. Glass has the highest flexural modulus among the three materials, with a value of 127.45 MPa, making it the stiffest among the three composite materials. Hence, jute is the most flexible material among the three, with a high strain value, making it suitable for applications that require flexibility. Glass composite is the stiffest and strongest material, making it suitable for high-strength applications. A high flexural modulus of glass fiber composite indicates that the material is stiff, which is good for composite leaf springs. This is because stiff material is more capable of supporting heavy loads, which is important for leaf springs in automotive applications.

6.3 Comparison of Impact Strength of Composite

The Charpy test was performed according to A370 standard for measuring the impact strength and comparison of obtained results are shown in bar chart of Figure 15. It has been seen that the values of average impact strength from the experimental investigation are 23.12 j/cm², 73.42 j/cm², 37.54 j/cm² for jute, glass and hybrid composite respectively. However, glass fiber exhibits high impact strength due to its high resistance to stress propagation. The maximum impact strength (74.82 J/cm²) obtained for glass fiber composite of sample 3. On the other hand, jute fiber has the lowest average impact strength (23.12 J/cm²) and hybrid composite's impact strength was found to be 37.54 J/cm². Standard deviation has been shown on bar chart for each composite's obtained mean impact strength value, as it shows how dispersed the data is in relation to mean value. Glass fiber has a lower standard deviation (± 2.03) than jute and hybrid composites (± 3.13 , ± 3.97 , respectively). As glass fiber has low standard deviation hence, obtained values of impact strength for each sample are close to the mean, whereas for other two composites, the sample's values are a little bit spread out from the mean value. This is because glass fibers have a higher tensile strength and modulus compared to jute fibers, when combined with a suitable matrix material, such as a polymer resin, the resulting composite will have improved mechanical properties, including increased impact strength and obtained result for glass fiber is its evidence.

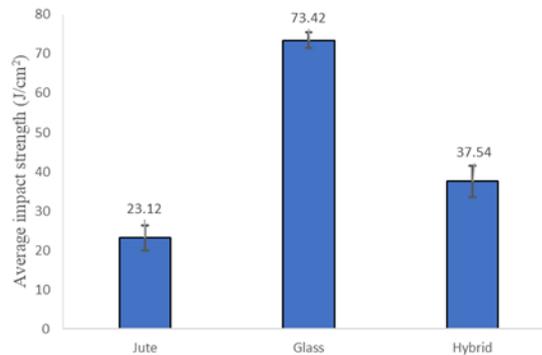


Figure 15. Impact strength comparison of all composites

In addition, the presence of glass fibers in the hybrid composite will contribute to the overall improvement in mechanical properties. However, the impact strength value of the hybrid composite still be lower compared to the woven glass fiber composite, due to the presence of lower strength jute fibers in the composite structure. Overall, the woven glass fiber composite is the best option in terms of mechanical performance, based on its higher impact strength value compared to the other composites. As the glass fiber has the highest energy absorption ability, it can be used in leaf spring applications.

7. Numerical Analysis Results

7.1 Stress Comparison

Both models are subjected to structural analysis, where the distribution of stress is observed, and the results of the static structural analysis indicate that the composite structure leaf spring has a lower stress concentration compared to the other model. According to the contour, the maximum bending stress occurs at the two ends of the supports. This is shown through the comparison of the von Mises stress distribution in Figure 16(a), and (b). The analysis was performed under a constant load of 13670 N and similar loading conditions, with the boundary conditions remaining constant for both models.

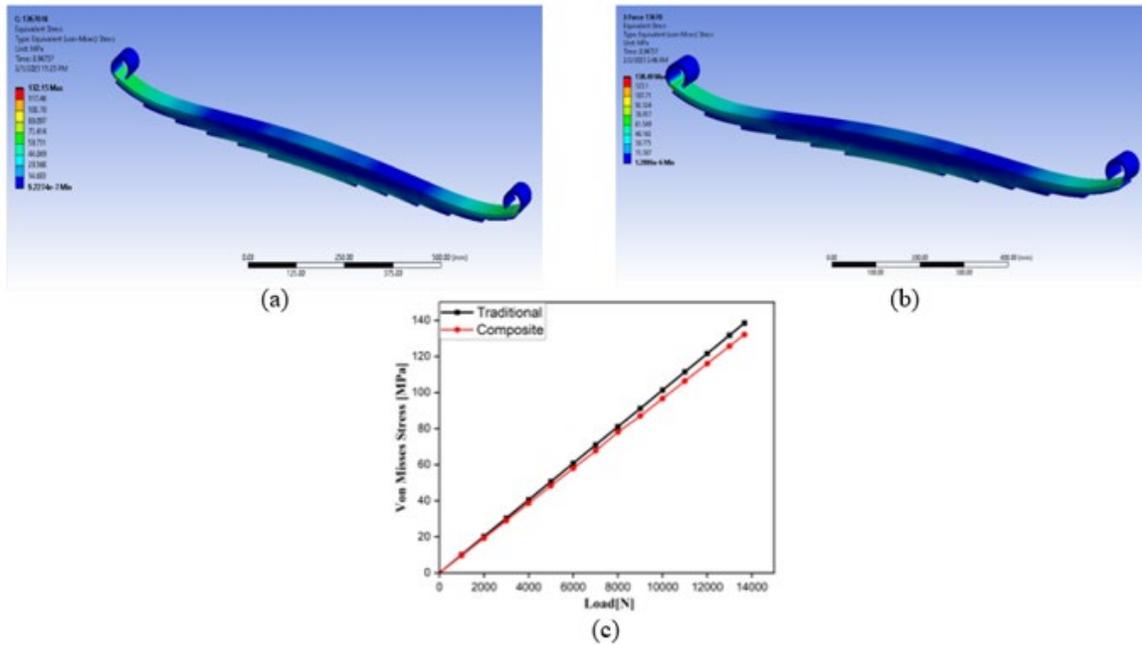


Figure 16. (a) Stress distribution for composite leaf spring, (b) Stress distribution for traditional leaf spring, and (c) Stress vs Load comparison graph of traditional and composite leaf spring

The maximum Von Mises stress for the traditional material is 138.49 MPa, and for the composite material, it is 132.15 MPa, under a maximum static loading condition of 13670 N. This indicates a stress reduction of 4.58% for the composite material compared to the traditional material. The reduction in stress is due to the superior properties of the composite material. Composites typically have a higher strength-to-weight ratio and better fatigue resistance compared to traditional materials such as steel. This means that the composite material can handle a similar load while experiencing a lower stress level, leading to improved durability and a reduced risk of failure

7.2 Deformation Comparison

After conducting a static structural analysis on two models, it was observed that the composite structure leaf spring experienced a greater amount of deformation compared to the other model. The analysis results are depicted in contour maps in figures 17(a), and (b), which showed that the maximum deformation occurred at the middle section of both structures

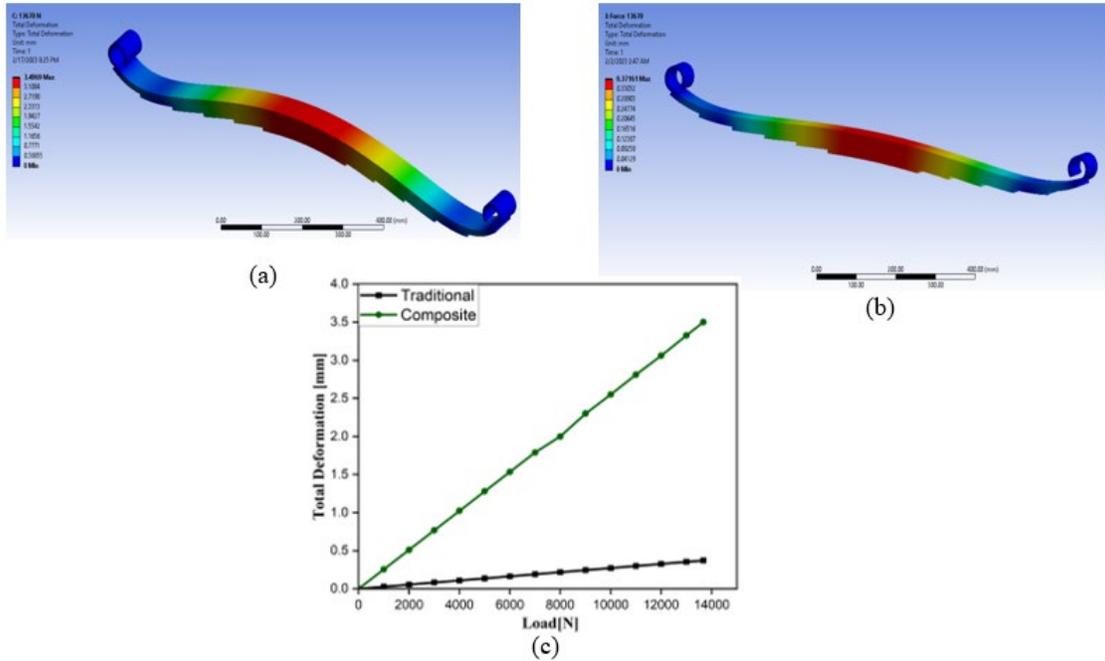


Figure 17. (a) Deformation for composite leaf spring, (b) Deformation for traditional leaf spring, and (c) Deformation vs load comparison graph of traditional and composite leaf spring

The deflection for both leaves is also analyzed. Structural steel leaf springs have less total deformation than composite leaf springs, but the difference gets larger as the load increases. From Figures 17(a), and (b), it can be observed that the traditional leaf spring deflected 0.3716 mm, whereas the composite structure leaf spring deflected 3.49 mm, which is 89.36% more. The main reason for the higher deformation in the composite leaf spring compared to the traditional structural steel leaf spring is likely due to the difference in their material properties. As woven glass fiber, tend to have lower stiffness and strength compared to metals like structural steel, hence it tends to deform more under load. A higher deformation can be desirable to absorb shocks and vibrations. On the other hand, excessive deformation can lead to failure or reduced performance.

7.3 Strain Energy Comparison

Total strain energy contour for both models at maximum loading condition is shown in figures 18(a), and (b). From the figure 18(c) the strain energy is almost the same when the load is minimal, but it starts to fluctuate when the load increases. It can be observed that energy absorption by the traditional leaf is 0.682mJ and for composite leaf spring it is 6.73mJ at maximum loading condition which is an increase of 89.86%. Where high strength and stability are required, such as in heavy-duty vehicles, the higher strain energy of the composite leaf spring is not desirable because it indicates that leaf spring may deform more and store more energy, potentially leading to reduced performance or failure.

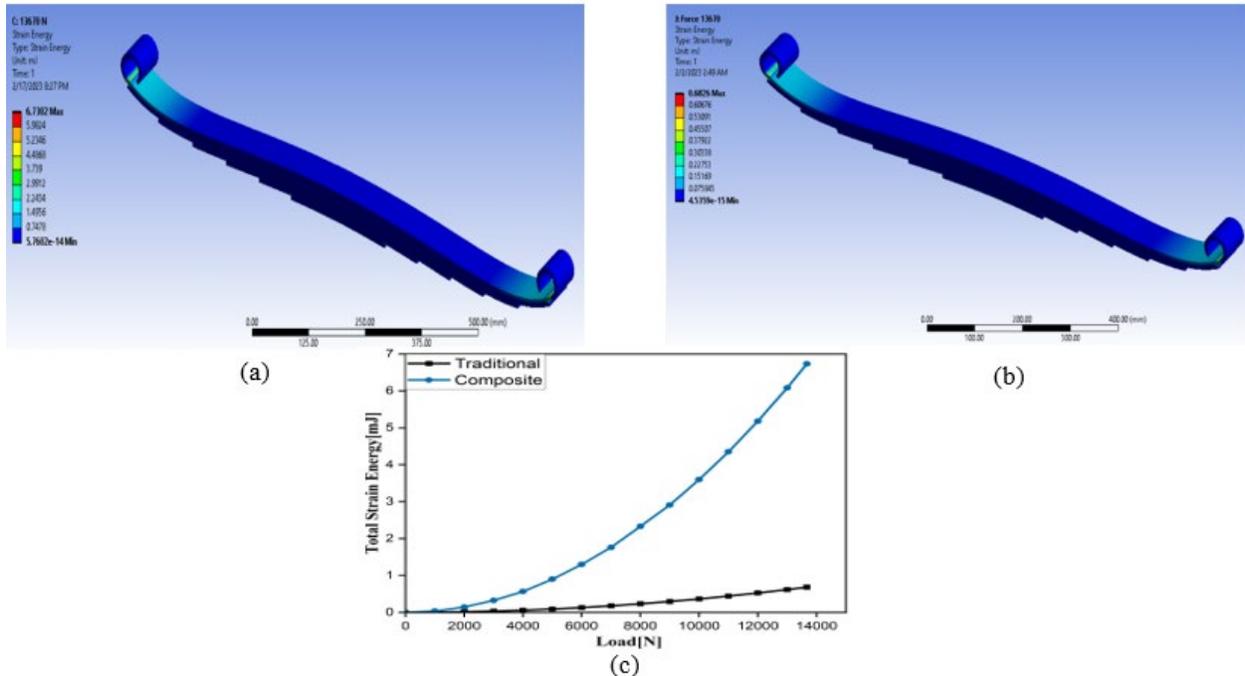


Figure 18. (a) Total strain energy for composite leaf spring, (b) Total strain energy for traditional leaf spring, and (c) Strain energy vs load comparison graph of traditional and composite leaf spring

Whether high strain energy in a composite leaf spring compared to a structural steel leaf spring is good or bad depends on the specific design requirements and intended use of the leaf spring. The higher deformation capacity means high strain energy of the composite leaf spring is desirable to absorb shocks and vibrations. Hence, E-glass composite leaf spring has a higher capacity to absorb energy and deform without failing.

7.4 Modal Analysis

Modal analysis is a technique used to study the natural modes of vibration of a structure or system. It involves determining the natural frequencies, damping ratios, and mode shapes of the system under consideration. To determine the vibration characteristics of the structure (natural frequencies and mode shape), modal analysis is performed on both models (composite and conventional leaf spring). The results are presented in Table 13. It establishes the leaf spring's natural frequencies to confirm that they are distinct from the excitation frequencies, upholding safety criteria. In Figures 19(a) - (f), the corresponding mode forms are displayed. Harmonic response analysis is the method used to discover the natural frequencies at which maximum amplitude, and hence resonance, occurs in the structure. Both models have the same boundary conditions. Since the system is thought to be a three-DOF system, the first three modal frequencies are relevant.

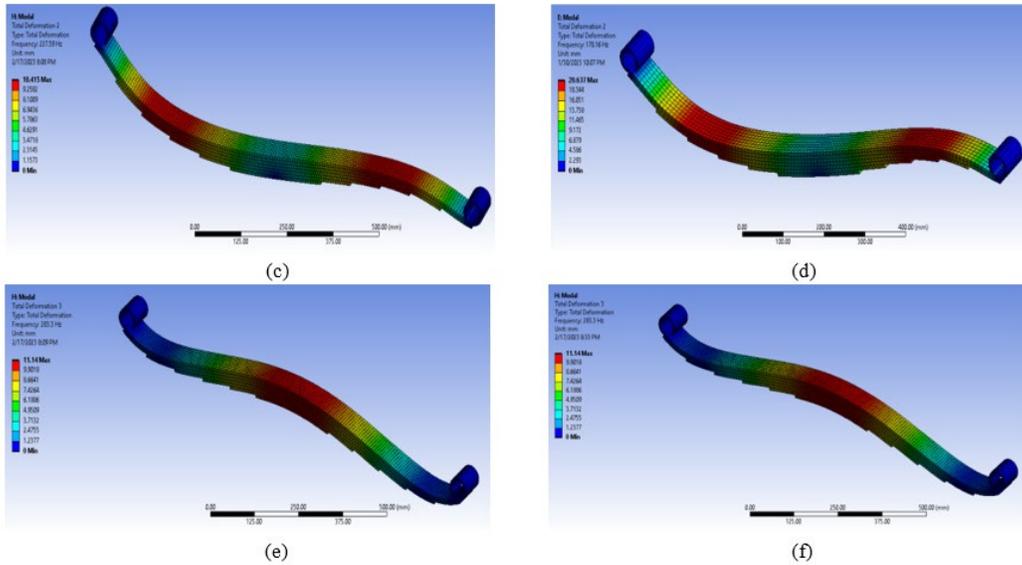


Figure 19. (a) Frequency response of composite leaf spring, (b) Frequency response of traditional leaf spring

Table 11. Modal frequencies of composite and traditional leaf spring

Modes	Composite leaf spring frequency (Hz)	Conventional leaf spring frequency (Hz)
1	191.02	121.24
2	227.59	178.16
3	283.3	238.96

7.5 Harmonic Response Analysis

Harmonic Response Analysis is a type of structural analysis that is used to determine the response of a structure subjected to a harmonic load, such as vibration. The aim of the analysis is to predict the vibration frequencies and the corresponding amplitudes and modes of vibration of the structure. In the case of a leaf spring, harmonic response analysis can be used to predict the behavior of the spring under different loading conditions, such as harmonic loads produced by road inputs, and determine its resonant frequencies and vibration modes. This information can be used to optimize the design of the leaf spring and improve its performance in terms of stiffness, damping, and durability. From Figures 20 (a) - (b), it is noticed that the leaf spring structure excites most at the third modal frequency (283.3 Hz) for a composite structured leaf spring, which is hence considered its natural frequency. Similarly, in a traditional leaf spring, the second modal frequency (178.16 Hz) is equal to its natural frequency and excites most. It is also observed that the natural frequency of a composite leaf spring is at its maximum.

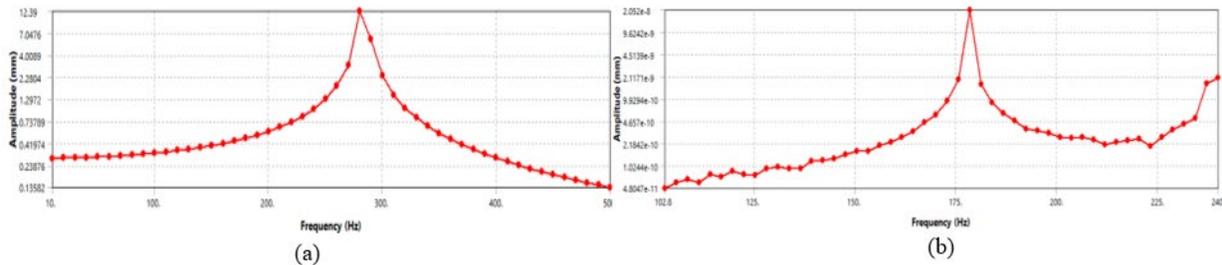


Figure 20. (a) Frequency response of composite leaf spring, (b) Frequency response of traditional leaf spring

The higher natural frequency of a composite leaf spring (283.3 Hz) compared to a traditional leaf spring (238.96 Hz) indicates that the composite leaf spring has a higher resistance to vibrational motion at that frequency compared to the traditional spring. This means that for a given excitation frequency, the composite spring will vibrate less than the traditional spring. The higher natural frequency can be a result of differences in material properties, geometry, or

manufacturing processes between the two types of springs. As the natural frequency of woven E-glass epoxy composite leaf spring is greater than the conventional leaf spring, hence the structure can avoid the resonance from road frequency.

7.6 Weight Comparison

For comparing the weight of traditional (steel) and composite leaf springs, Figure 21 bar chart was created. The comparison of leaf spring weights (kg) for steel and composite materials is shown in the bar chart above. It is easy to see that the weight of the composite leaf spring has decreased by 75.16% compared to the traditional leaf spring. The weight of a steel leaf spring is 20.94 kg, while that of a composite leaf spring is 5.2 kg. This weight reduction of composite leaf spring by 75.16% can have a significant impact on the fuel efficiency and overall performance of the vehicle by reducing its carbon footprint. This is because the energy required to move a vehicle is directly proportional to its weight. The heavier the vehicle, the more energy is required to move it, and the more fuel is consumed. Therefore, reducing the weight of a vehicle can significantly reduce its fuel consumption, resulting in reduced carbon emissions.

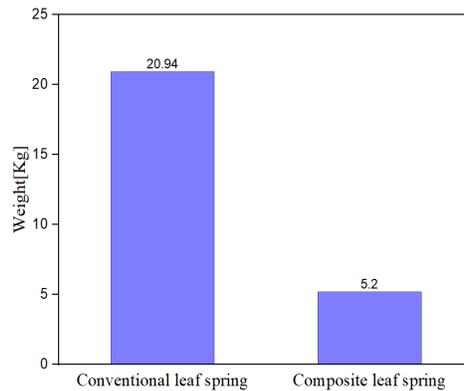


Figure 21. Weight comparison of leaf spring

8. Conclusion

The purpose of this research was to investigate the suitability of a jute or E-glass or hybrid fiber-reinforced hybrid composite material for leaf spring applications. The study involved conducting experimental tests and numerical simulations. In the experimental analysis, the tensile, flexural, and impact tests were carried out on a woven jute, E-glass, and a hybrid composite sample. The experimental research in this thesis indicated that E-glass fiber reinforced composite can replace steel leaf springs due to its higher tensile, flexural, and impact strengths than jute composite. The numerical analysis was then carried out to further investigate the various parameters of the E-glass composite leaf spring in comparison to traditional steel leaf springs. The simulation results showed that the stress in the composite leaf spring was reduced by 4.58% while the deformation increased by 89.36%. The strain energy also increased by 89.96%, and there was a significant weight reduction of 75.16% which will result in better comfort on the road for the passengers and provide an overall smoother ride when compared to traditional steel leaf springs.

Weight reduction by 75.16% of composite leaf spring can improve fuel efficiency and vehicle performance while lowering its carbon footprint. The reduced stress and increased strain energy indicate that the E-glass composite leaf spring is less likely to fail under pressure, improving vehicle safety and reliability. Even though composite leaf springs possess favorable properties, the automotive industry still prefers to use steel leaf springs due to the cost factor. This is because the manufacturing process for composite materials is more expensive compared to steel. The cost of producing E-glass composite material for manufacturing the spring is estimated to be in the range of 40-55 USD per square foot, which is notably higher compared to the cost of steel that ranges from 16-20 USD per square foot. However, the study provides a valuable insight into the potential of E-glass composite as a viable alternative to traditional materials in leaf spring applications.

9. Future Works

Only the material of the leaf spring was changed in this investigation, and outcomes in terms of stress distribution and energy absorption were much improved. There are several possible future works that can be carried out to further enhance the research work conducted in this thesis. Some of these future works are:

1. Further study can be conducted by replacing the leaves with honeycombs structure by changing geometry.
2. Conducting fatigue tests on the E-glass composite leaf spring to investigate its long-term durability and ability to withstand cyclic loading. This is particularly important as leaf springs are subjected to repeated loading and unloading during vehicle use.
3. Investigating the effect of different orientation and combinations of jute and E-glass fibers on the mechanical properties of the composite material. The current study focused on a specific Woven alignment of E-glass fiber; however, other combinations could be explored to determine their potential.

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Biographies

Md. Hozzatul Islam was a student (or academic) in the Department of Mechanical Engineering at Khulna University of Engineering and Technology (KUET), Khulna, Bangladesh. He has built strong fundamentals in core mechanical engineering, and shows interest in areas such as design, thermodynamics, manufacturing, and possibly robotics/automation while reflecting the broad scope typical in his department. Beyond coursework, Md. Islam is motivated to apply engineering knowledge to real-world problems, particularly in sustainable and practical mechanical systems. His future ambitions include engaging in research projects or industry work that could contribute towards Bangladesh's infrastructure and manufacturing sectors.

Joy Ganguly was a student (or academic) in the Department of Mechanical Engineering at KUET, Bangladesh. During his time at KUET, he has developed a keen interest in mechanical design, fluid mechanics, and thermal systems. Alongside his academic coursework, Joy has been exploring how mechanical engineering principles can be leveraged for sustainable energy applications and industrial solutions. He is also interested in collaborative research and enjoys participating in team-based projects that combine theoretical learning with hands-on system modeling and experimentation. Joy aims to contribute to the development of efficient mechanical systems relevant to Bangladesh's industrial context.

Md. Radwanul Kabir studies in the Department of Mechanical Engineering at KUET, Khulna, Bangladesh. He has a strong interest in fluid dynamics, heat transfer, and computational modeling — areas that align with modern mechanical engineering challenges. Radwanul is particularly drawn to research involving flow behavior, energy systems, and thermal management. Beyond his academic studies, Radwanul hopes to work on projects that integrate mechanical engineering with sustainable technologies, such as renewable energy or efficient heating/cooling systems for industrial and environmental applications.

Nurul Hasnat is a graduate of the Department of Mechanical Engineering at Khulna University of Engineering & Technology (KUET), Bangladesh. During his undergraduate studies, he gained research experience in composite laminate fabrication, finite-element and representative volume element (RVE) analysis of composite structures, and exploratory work on geopolymer-based cementitious materials. He was a former member of a Formula Student recognized team, overseeing aerodynamic package development and fiber reinforced vehicle body construction, and also worked as an Administrative Assistant for an engineering journal, supporting editorial and review workflows. His current research interests include composite materials, solid mechanics, and the development and characterization of advanced structural and cementitious materials.

Nazmus Sakib is affiliated with the Department of Mechanical Engineering at KUET, Khulna, Bangladesh. His focus during his studies includes mechanical design, materials science, and the foundational principles of machine dynamics and thermodynamics. Nazmus is interested in exploring how mechanical engineering can intersect with contemporary needs, for instance, sustainable manufacturing or lightweight material design. He is also curious about future developments in mechanical engineering in Bangladesh, and hopes to contribute either through academic research or by working in industry to help build efficient, low-cost mechanical systems for production, infrastructure, or energy applications.

Md. Tanvir Ahmed is associated with the Department of Mechanical Engineering at Khulna University of Engineering and Technology (KUET), Khulna, Bangladesh. He currently works as a Research Assistant in the department, where he has co-authored research on composite materials and energy-absorption structures, for example, a recent paper on “Numerical Optimization of Auxetic Structures for Energy Absorption Applications.” One of his research interests involves sustainable materials: he has worked on the effect of eggshell-powder reinforcement in jute-fiber-reinforced fiber-metal laminates (FMLs), exploring how natural fillers influence mechanical properties. In addition to research, Tanvir has industrial engagement experience: he has worked as a Sales Engineer at Atlas Copco, which suggests he aims to blend academic expertise with industry-level applications. Beyond academics and work, Tanvir is likely motivated by bridging theoretical engineering and practical solutions, especially in materials engineering, sustainable composites, and mechanical design, offering promise for contributions in research or industrial sectors.

Muhammad Jawad Zin Noor is a Mechanical Engineering alumnus (or former student) of KUET, Bangladesh. During his time at KUET, he was actively involved in extra-curricular engineering-related projects: for instance, he served as Suspension System Expert for a project team under KILO FLIGHT. He also held a voluntary/executive role at the KUET Automobile Club, indicating interest and participation in automotive and mechanical-systems related activities beyond regular coursework. Jawad is passionate about product development, mechanical design, and applied mechanical engineering — with a leaning toward industrial R&D and hands-on mechanical system design and development. In short, he represents a well-rounded mechanical engineer with both academic grounding and practical project experience, ready to contribute to R&D or industry-level mechanical and automotive engineering challenges.