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Modelling, Analysis, Fabrication and Experimental Testing of Leaf Spring Material by Hybrid Composite Materials with Natural Fiber for Electric Vehicle

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Abstract

Present automobiles are running with the help of fuel. But in the future, electricity plays a significant role. The generation upgrading into electricity as the main source. Leaf springs are used for suspension for automobiles. These leaf springs are manufactured with stainless steel material. This is heavy in weight, which is one of the limitations for consuming of fuel. If this material is used in electric vehicle, it consumes more electricity. To overcome this issue the material is replaced with composites. The primary goal of this endeavour is to achieve weight rebates without diminishing in reliability. A parametric study of the leaf spring by varying the three-dimensional parameters will be carried out. Fabrication of the composite specimen is based upon the ASTM standard. Modelling and analysis of composite leaf spring with SOLIDWORKS and ANSYS WORKBENCH software. Epoxy resin and E- glass fibre is reinforced with various fractions of Prosopis Juliflora (Throne powder) composites were falsification by hand layup technique. The fabricated composite material in the form of plate were cut into corresponding profiles as per ASTM standard. The objective is to examine the Stress, Strain, Deformation, Physical property, Mechanical properties, Thermal property of composite leaf spring with that of steel, CFRP.

Keywords: E-Glass Fiber, Prosopis Juliflora, Solid works, Ansys Workbench, Epoxy Resin.

I. INTRODUCTION

In comparison to a helical spring, a leaf spring has the benefit that its end may be guided along a certain direction. A helical spring prohibits this from happening. Steel leaf springs have a higher weight than other materials, which increases fuel consumption. Composite materials, revolutionizing traditional leaf spring design, are now integral in automotive engineering. The use of composites in leaf springs results in reduced weight, improves mechanical properties and energy efficiency in vehicles. This innovation contributes to enhanced performance, fuel efficiency, and overall sustainability in the automotive industry, marking a significant shift from conventional metal-based leaf springs to advanced composite solutions. While the inclusion of fibre in a composite increases its mechanical characteristics, the major role of the matrix is to transmit stresses between the reinforced fibre particles and protect them from mechanical and environmental damage. Leaf springs for electric vehicles (EVs) play a crucial role in optimizing the performance, efficiency, and sustainability of these advanced automotive systems. Unlike traditional internal combustion engine vehicles, EVs demand unique engineering considerations. The leaf springs in electric vehicles are designed to accommodate the specific weight distribution of batteries, providing support while maintaining a balance between ride comfort and handling. Materials like lightweight composites are often employed to enhance energy efficiency and reduce overall vehicle weight, contributing to extended battery range. The evolution of leaf spring technology in the context of electric mobility signifies a commitment to enhancing both environmental sustainability and driving experience in the rapidly advancing field of electric transportation. In this particular piece of work, a seven-leaf steel springs that are often seen in passenger automobiles is changed out for a composite multi-leaf spring that is created out of glass and epoxy composites. In present work, hybrid composites were manufactured with different weight fractions of reinforcement and with different weight percentages of different fibers. These specimens were tested according to the procedure mentioned in ASTM standard (American society for Testing and Materials). The effect of natural fiber reinforcement on glass fibre reinforced composite was studied and mechanical properties were analysed. In the field of mechanical engineering, incorporating E-glass fibres with Prosopis juliflora could lead to innovative composite materials. E-glass fibres, known for their high tensile strength, could reinforce the composite, making it suitable for structural components. Prosopis juliflora, with its natural abundance and resilience, might serve as a sustainable matrix material. This combination could open doors to lightweight and durable solutions in areas like aerospace, automotive, and manufacturing, aligning with the growing demand for eco-friendly materials in engineering applications.

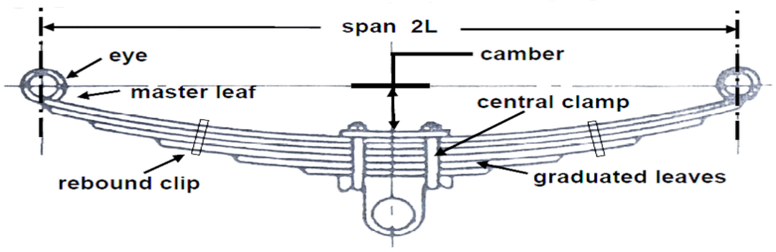


Fig.1. leaf spring

II. MATERIALS

1) MATERIALS SELECTION FOR CONVENTINONAL STEEL LEAF SPRING

Table 1: Material properties of steel

Property	STEEL
Youngs modulus	2E+11 Pa
Poisson's ratio	0.3
Density	7850Kg/m^3
Bulk Modulus	1.6E+11 Pa
Shear Modulus	7.6E+ 10 Pa

The data is gathered from the Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1

2) MATERIALS SELECTION FOR CONVENTINONAL STEEL LEAF SPRING

Table 2: Material properties of CFRP

Property	CFRP
Youngs modulus	7E+10 Pa
Poisson's ratio	0.2
Density	2000Kg/m^3
Bulk Modulus	3.8E+ 10 Pa
Shear Modulus	2.9E+10 Pa

3) *MATERIALS SELECTION FOR COMPOSITE LEAF SPRING*

Table 3: Material properties of GFRP

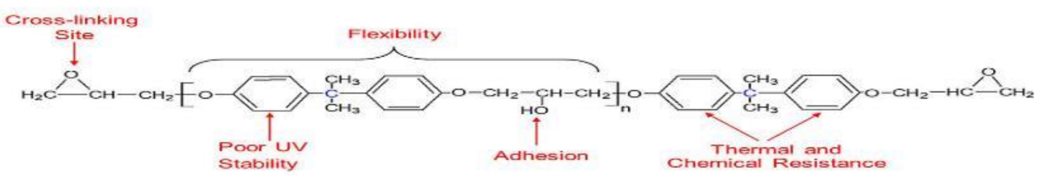
Property	GFRP with PROSOPIS JULIFLORA
Youngs modulus	5.25E+ 10 Pa
Poisson's ratio	0.21
Density	1340Kg/m^3
Bulk Modulus	3.01E+10 Pa
Shear Modulus	2.1E+ 10 Pa

4) EPOXY RESIN (LY-556): Bisphenol-A diglycidyl ether (C21H24O4) is another name for it. The actual resin is composed of epichlorohydrin and biphenyl (of which there are several types). A mixture of acetone and phenol is the most prevalent kind of biphenyl. When cured, epoxy resins offer "rigid but tough bond lines and have excellent adhesion to metals," according to adhesives.org. Epoxy Resin's characteristics (LY-556). The characteristics of Epoxy Resin (LY-556) are displayed in Table 4.4. This resin forms a robust connection with natural fiber.

Table 4 Properties of Epoxy Resin (LY-556)

S.No.	Parameter	Value
1	Modulus of elasticity	25 – 30Gpa
2	Poisson's ratio	0.33
3	Elongation	2 – 4%
4	Shear modulus	1.25Gpa

Fig.2 Epoxy resin LY556



5) HARDENER (HY-951): $C_6H_{18}N_4$ Hardener is a curing agent for epoxy or fiberglass. A hardener, also known as a catalyst, is needed for epoxy resin in order to start the curing process. It solidifies the adhesive when combined with resin. The final properties and appropriateness of the epoxy coating for a particular environment are determined by the particular choice and combination of hardener and epoxy components.

Table.5 Properties of Hardener (HY-951):

S.No.	Parameter	Value
1	Appearance	Reddish Brown
2	Colour	Colourless
3	Amine value	310 – 350mgKOH/g
4	Viscosity 25°C	3000cPs(max)
5	Density 25°C	0.98 – 1.00gm/cm^3
6	Flash point	81°C

Fig.3 Hardener HY951

6) PROSOPIS JULIFLORA: Prosopis juliflora is a type of mesquite shrub or small tree in the Fabaceae family. It is indigenous to the Caribbean, South America, and Mexico. In Africa, Asia, Australia, and other places, it has established itself as an invasive weed. It plays a part in the ongoing spread of malaria, particularly during arid spells when mosquitoes have less access to sugar-producing local plant sources.

Fig.4 Natural Fiber of Prosopis Juliflora

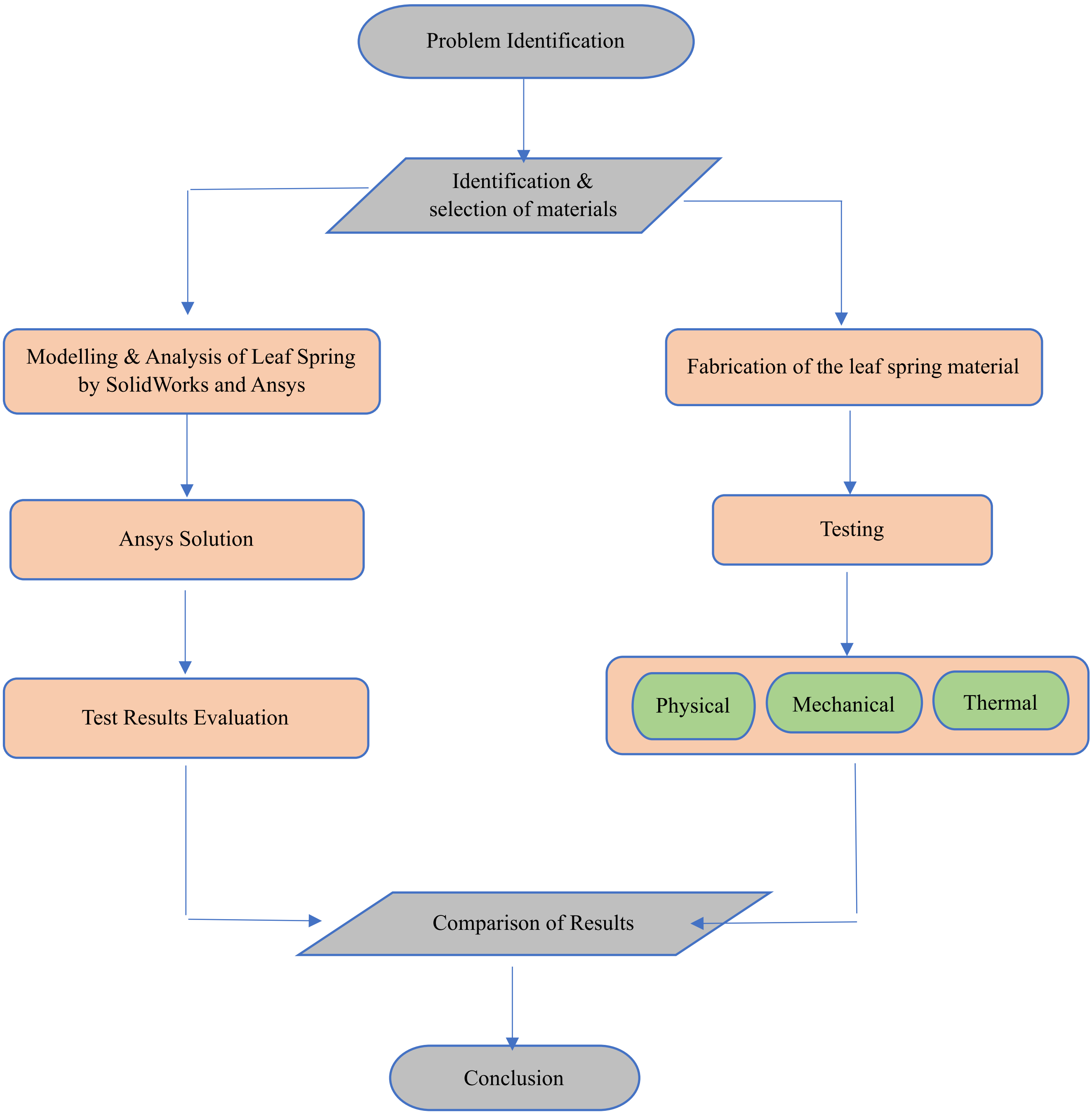
7)E-GLASS FIBER: E-glass fiber with a weight of 700gsm is a specific type of reinforcement material used in composite manufacturing. Its higher weight indicates a denser arrangement of fibers, providing increased strength and stiffness. The choice of this material would depend on the specific requirements of the application and the desired mechanical properties of the final composite product.

Table.6. Properties of Glass fiber

S. No.	**Parameter**	**Value**
1	Modulus of elasticity	75Gpa
2	Poisson’s ratio	0.25
3	Temperature	550 °C
4	Density	2.55 g/cm³

Fig.5. E- GLASS Fiber 700gsm

III. METHODOLOGY



A) MODELLING OF LEAF SPRING

The modelling of the leaf spring is done in SOLIDWORKS 2022. The SOLIDWORKS assembly drawing area is where all of the leaves, clamps, and graduated leaves are assembled after being individually designed in the part drawing. By creating surface contact between one leaf's top surface and bottom surface, the leaves are put together. In this manner, every leaf is put together in SOLIWORKS, and the clamps are then put together in the leaf spring. For modeling purposes, the leaf spring is used from the TATA ACE micro vehicle reference.

Table 7. Specification of leaf spring:

Design Parameter	Value (mm)
Total Length of spring (L)	1072
Eye Inner & Outer Dia	25 & 41
Thickness (t)	8
Width (b)	60
Radius of the Master Leaf	1250

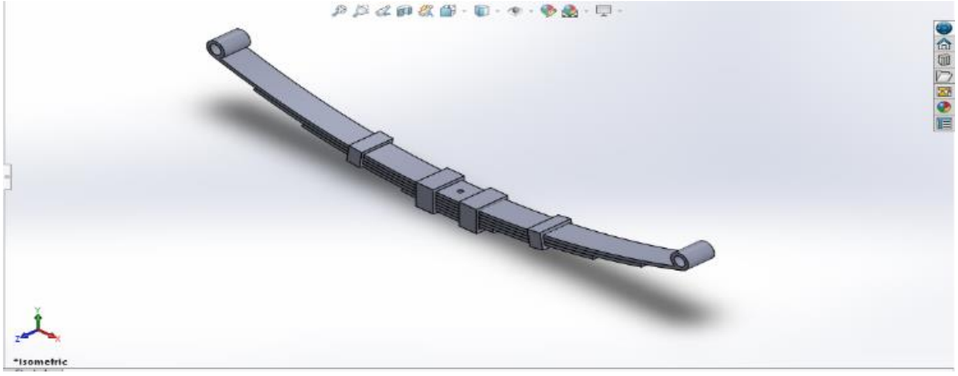


Fig.6. assembled figure of Leaf spring in SolidWorks

B) STATIC ANALYSIS OF LEAF SPRING

Static analysis was carried out using ANSYS19.2 software. For this study, static structural analysis is used. The geometry is imported to the ansys workbench using .iges format

MESHING

The process of meshing entails breaking the model up into smaller units known as elements. The leaf spring's crisp curves make it easier to choose the free mesh since the object's shape won't change. The element type must be chosen before meshing the leaf spring.

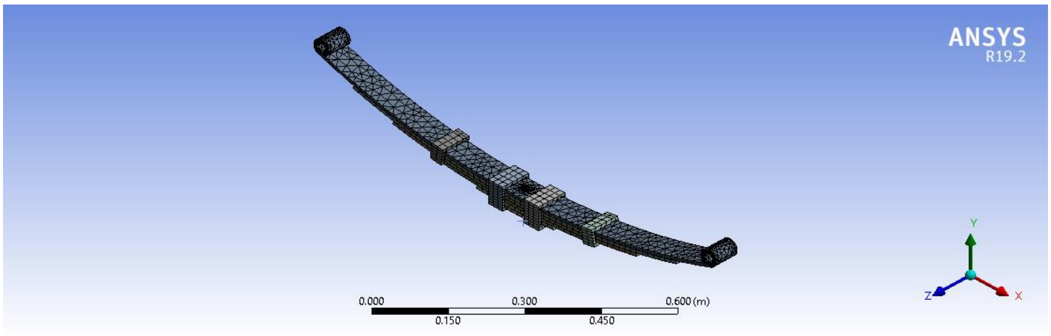


Fig.7. Meshing of Leaf spring in Ansys

Statistics	
Bodies	10
Active Bodies	10
Nodes	24954
Elements	9788
Mesh Metric	None

Fig.8. Nodes and Elements of Leaf spring in Ansys

BOUNDARY CONDITION

A clamp holds the leaves together. While the opposite end is fastened to a short swinging arm via a shackle, the front end is fastened to the frame. The metal leaves are perpendicular to the road and bend toward it, and the leaf springs flatten when force is applied, helping to cushion the bumps and jolts of the journey. As a result, fixed support is given at the inner surface of the eye region and a load of 10kN is delivered to the base plate in the positive y-direction. To enable sliding without requiring separation between components, all contacts between leaf and leaf, leaf and bolt, leaf and nut, and leaf and bracket are built as no separation contacts.

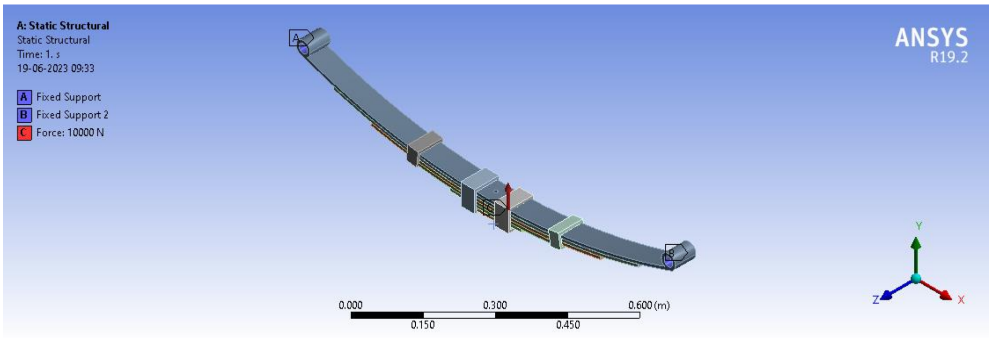


Fig.9. Boundary condition of Leaf spring in Ansys

C) FABRICATION OF LEAF SPRING

The hand lay-up process, which entails layering resin and reinforcing fibers by hand onto a mold, is used to fabricate composite leaf springs. Customization is possible thanks to this economical procedure, which guarantees exact fiber orientation thanks to trained labor. The end resultant leaf springs meet certain automobile needs with strength, durability, and weight advantages. For experimental testing, the specimen is sliced in accordance with ASTM standard.

fig.10. Fabrication material

IV. RESULT AND DISCUSSIONS

STATIC STRUCTURAL ANALYSIS

A) FE ANANLYSIS OF CONVENTIONAL STEEL, CFRP AND GFRP WITH PROSOPIS JULIFLORA LEAF SPRING

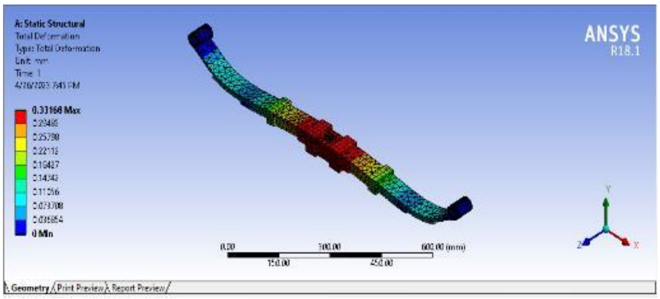


Fig. 11. Deformation (steel leaf spring)

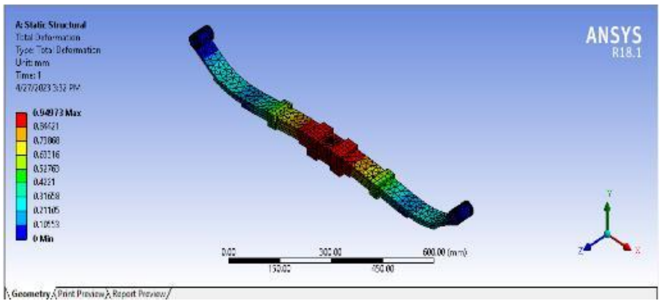


Fig.12. Deformation (CFRP leaf spring)

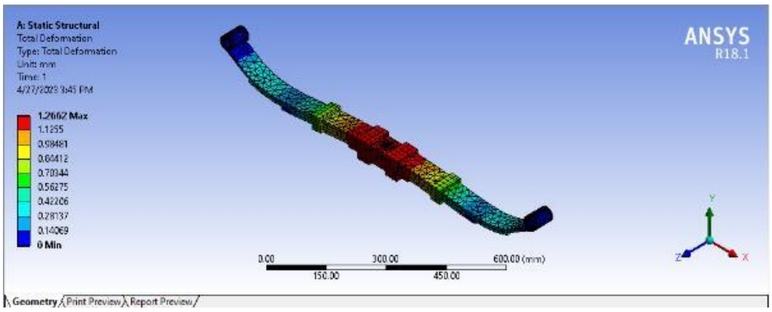


Fig. 13. Deformation (GFRP with Prosopis Juliflora leaf spring)

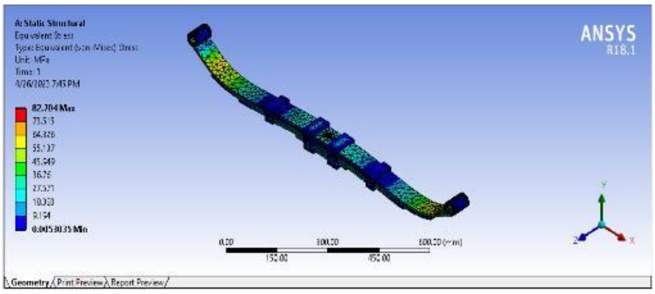


Fig. 14. Equivalent Stress (steel leaf spring)

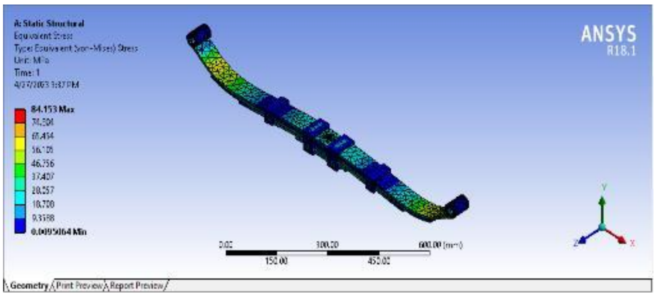


Fig. 15. Equivalent Stress (CFRP leaf spring)

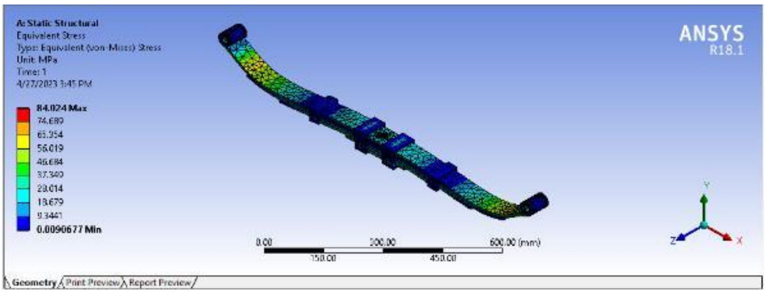


Fig. 16. Equivalent Stress (GFRP with Prosopis Juliflora leaf spring)

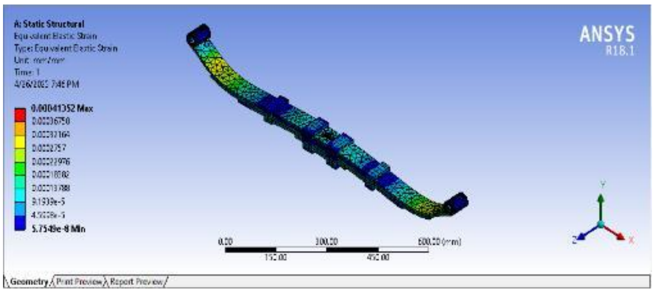


Fig. 17. Equivalent Elastic Strain (steel leaf spring)

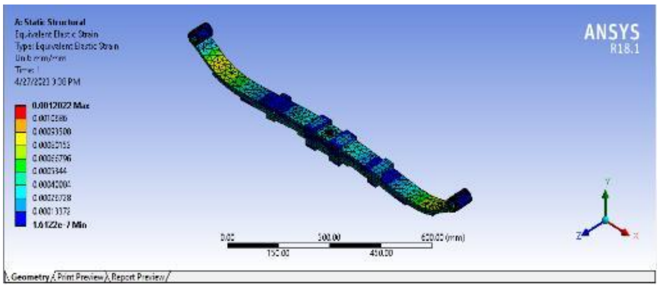


Fig. 18. Equivalent Elastic Strain (CFRP leaf spring)

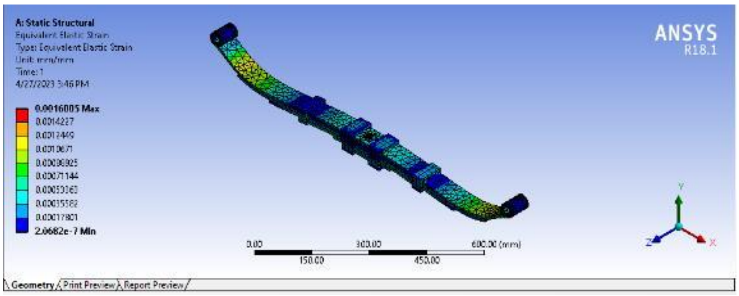


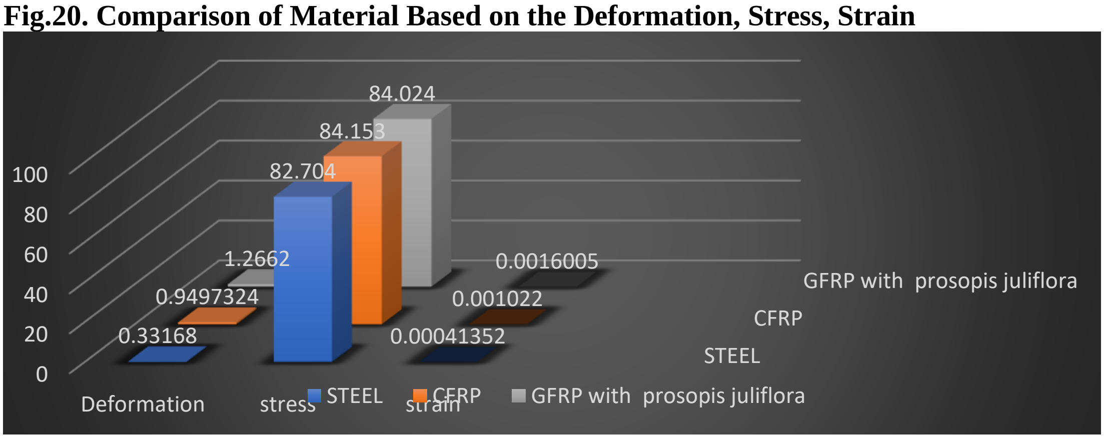
Fig.19. Equivalent Elastic Strain (GFRP with Prosopis Juliflora leaf spring)

B) FEA COMPARISON BETWEEN STEEL, CFRP AND GFRP WITH PROSOPIS JULIFLORA LEAF SPRINGS

TABLE 8. comparison between steel, CFRP, GFRP with PJ

PARAMETER	STEEL LEAF SPRING	CFRP	GFRP with PROSOPIS JULIFORA
DENSITY	7850 Kg/m^3	2000 Kg/m^3	1340Kg/m^3
LOAD	10KN	10KN	10KN
YOUNG'S MODULUS	2E+11	7E+10	5.2E+10
DEFORMATION	0.33168	0.94973mm	1.2662mm
STRESS	82.704Kg/m^2	84.153Kg/m^2	84.024Kg/m
STRAIN	0.00041352	0.0012022	0.0016005

Fig.20. Comparison of Material Based on the Deformation, Stress, Strain



EXPERIMENTAL TESTING

From the fabricated composites, the test specimens are prepared as per ASTM standards and are tested to evaluate their Physical Property, Mechanical Properties, Thermal Property. The results by conducting these tests are given below.

4.1 PHYSICAL PROPERTY
DENSITY Results:

In the research work, the testing of all the specimens held on Precision Weighing Machine model no: XS204. The result of weighing machine, weight of the sample in air, Weight of the sample in water are calculated and listed in below table.

Table.9. Variation in Density Results

specimen	Weight of the sample in air (a)	Weight of the sample in water (b)	Density = [a/(a-b)] *d g/cc
S1	1.781	1.703	2.283
S2	1.615	1.536	2.044
S3	1.547	1.468	1.958
S4	1.431	1.349	1.765
S5	1.34	1.24	1.34
S6	1.347	1.287	2.245

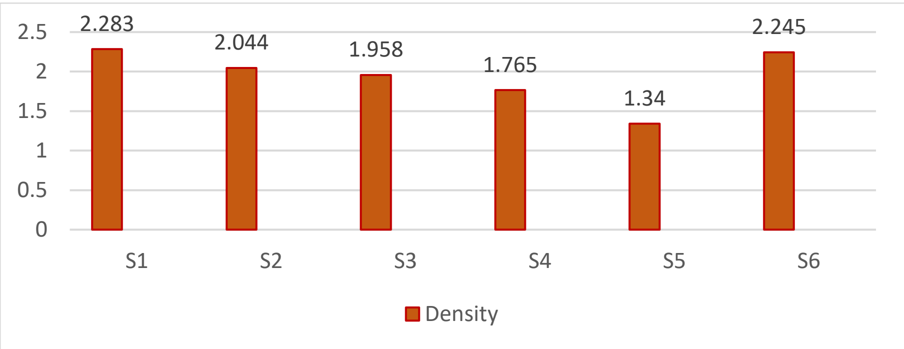


Fig.21. Variation of different Density for different specimens

4.2 MECHANICAL PROPERTIES

A) TENSILE TEST:
*ASTM D3039 – (250*25*4.5) mm*

In the research work, the testing of all the specimens was showed in universal testing machine. The result of universal testing machine, the ultimate tensile load, ultimate tensile strength is calculated and listed in below table.

Table 10. Variation in Tensile Test Results

specimen	Prosopis juliflora (grams)	Area of cross – section (mm^2)	Ultimate tensile load (KN)	Ultimate tensile strength (N/mm^2)
S1	10	108.23	23.3	215
S2	12	108.78	31.13	286
S3	14	111.9	28.36	253
S4	16	107.22	25.14	234.45
S5	18	104.04	34.23	329
S6	20	91.05	22.03	241.95

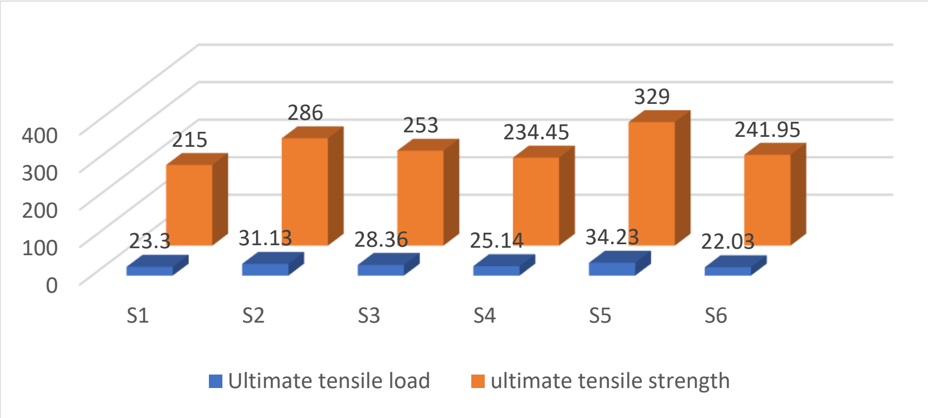


Fig.22. Variation of different tensile strength for different specimens at maximum tensile load

B) COMPRESSION TEST:

*ASTM D642 – (250*25*4) mm*

In the research work, the testing of all the specimens was showed in universal testing machine. The result of universal testing machine, the compression load, compression strength is calculated and listed in below table.

Table 11. Variation in Compression Test Results

specimen	Prosopis juliflora (grams)	Area of cross – section (mm^2)	Compression load (KN)	Compression strength (N/mm^2)
S1	10	98.97	1.54	15.56
S2	12	97.68	1.81	18.52
S3	14	98.02	2.43	24.79
S4	16	98.40	3.17	32.07
S5	18	98.83	3.51	35.51
S6	20	98.14	3.27	33.31

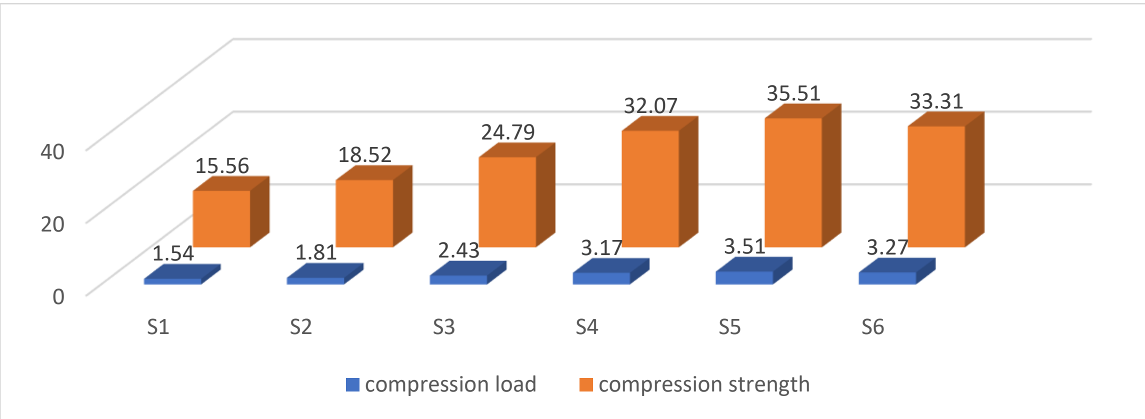


Fig.23. Variation of different compression strength for different specimens at maximum compression load

C) IMPACT STRENGTH:

*ASTM D760-06 (64*12.7*3.2) mm*

In the research work, the testing of all the specimens was done by the charpy impact testing machine. The result of charpy impact test, maximum loss of impact energy of specimen is noted and corresponding impact strength are calculated and listed in below table.

Table 12. Variation in Impact Test Results

specimen	Prosopis juliflora (grams)	Impact Energy (Joules)
S1	10	22.67
S2	12	27.66
S3	14	25.3
S4	16	24.33
S5	18	31.66
S6	20	22.67

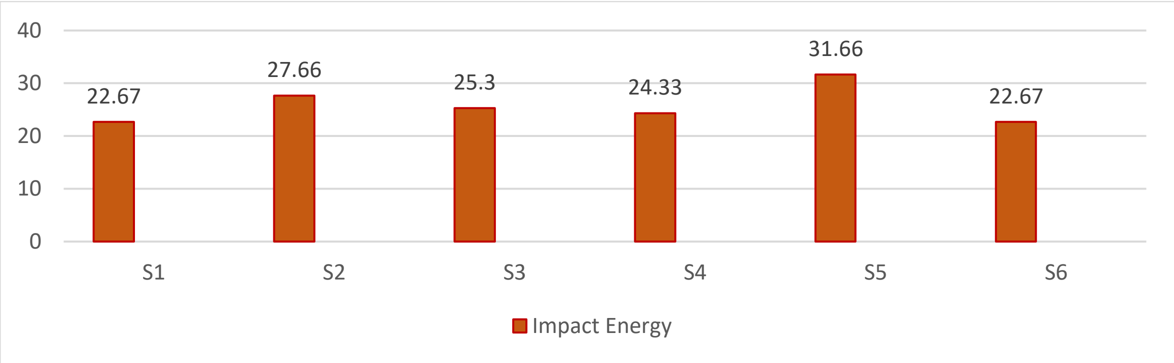


Fig.24. Variation of different Impact Energy for different specimens

D) Flexural Test:

*ASTM D790 - 17 (3.2*12.7*125) mm*

In the research work, the testing of all the specimens was showed in Flexural Testing Machine. The result of the Flexural load, Flexural strength is calculated and listed in below table.

Table 13. Variation in Flexural Test Results

specimen	Prosopis juliflora (grams)	Flexural load (N)	Flexural strength (N/mm^2)
S1	10	95.97	186
S2	12	109.9	213
S3	14	141.38	274
S4	16	159.44	309
S5	18	183.696	356
S6	20	153.25	297

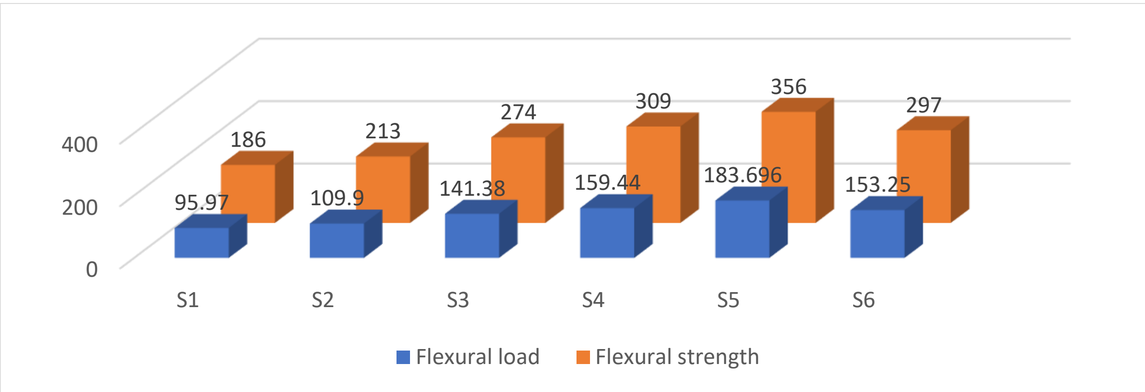


Fig.25. Variation of different flexural strength for different specimens at maximum flexural load

E) HARDNESS TEST: ASTM D785

Thickness ≥ 6 mm

Width ≥ 13 mm
Length ≥ 13 mm

Table 14. Variation in Hardness Test Results

specimen	Prosopis juliflora (grams)	Hardness range HRA
S1	10	41
S2	12	49
S3	14	53
S4	16	59
S5	18	64
S6	20	57

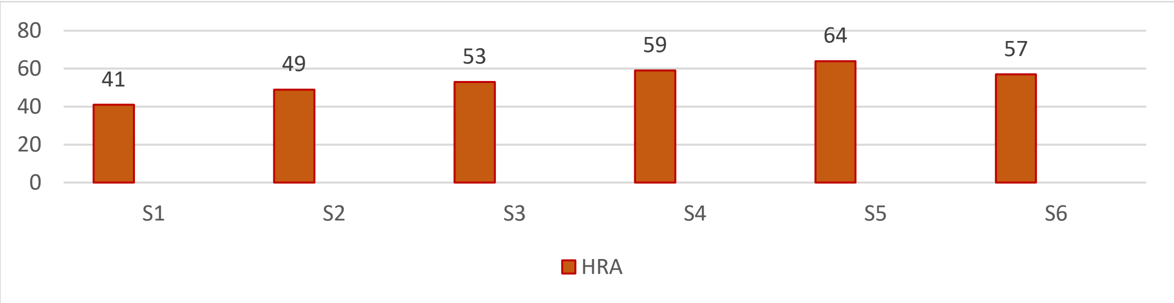


Fig.26. Variation of different Hardness for different specimens

4.3 THERMAL PROPERTY

COEFFICIENT OF LINEAR THERMAL EXPANSION: ASTM D696 -98
Length – 25 to 40 mm
Diameter – 10 mm

Table 15. Variation in CLTE Test Results

specimen	PJ %	Temperature °C	CTLE μ/°C
S1	10	175	6.33
S2	12	245	6.95
S3	14	305	7.27
S4	16	410	7.89
S5	18	600	8.6
S6	20	515	8.26

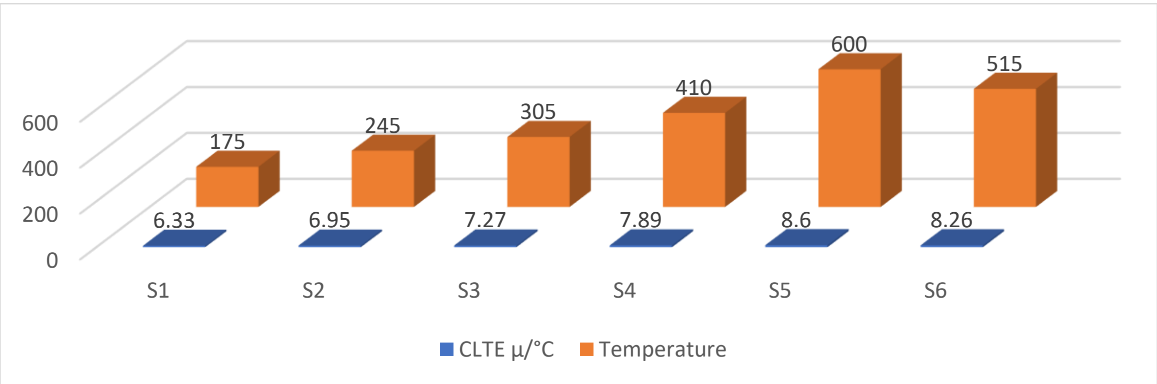


Fig.27. Variation of different CLTE for different specimens

Experimental Comparison between steel, CFRP, GFRP with prosopis juliflora Leaf Spring

Tab.16. Comparison of Material Based

Parameter	density	tensile	compression	Charpy	flexural	hardness	CLTE
Steel	8g/cc	295MPa	35MPa	24.5J/cm	174 MPa	52HRB	8.5 µ/°C
CFRP	2.25g/cc	133MPa	6.63MPa	15J/cm	22.6MPa	44.6HRC	1.3 µ/°C
GFRP with prosopis juliflora	1.34g/cc	329MPa	35.51MPa	31.66J/cm	356 MPa	64HRA	8.57 µ/°C

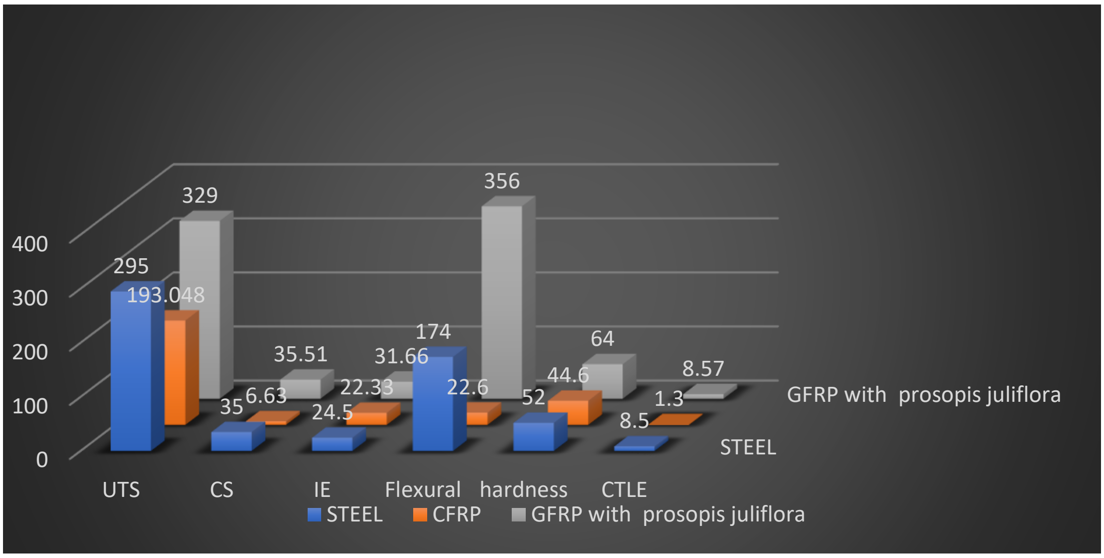


Fig.28. Variation of different materials at different Testings

V. CONCLUSIONS

Total Deformation: GFRP with Prosposis Julifora showed the highest total deformation of 1.2662 mm compared to Structural Steel (0.33168 mm) and CFRP (0.94973 mm). This indicates that GFRP with Prosposis Julifora can withstand higher loads without experiencing permanent deformation, making it a suitable material for a leafspring.
Equivalent stress: GFRP with Prosposis Julifora also exhibited a high equivalent stress of 84.024 MPa, which is higher than Structural Steel (82.704 MPa) and CFRP (84.153 MPa). This suggests that GFRP with Prosposis Julifora has high strength and can handle significant stress without failure, further supporting its suitability for a leafspring.
Equivalent elastic strain: The equivalent elastic strain of GFRP with Prosposis Julifora was 0.0016005 mm, which is higher than that of Structural Steel (0.00041352 mm) and CFRP (0.0012022 mm). This indicates that GFRP with Prosposis Julifora can withstand higher strains without undergoing plastic deformation, making it a desirable material for a leaf spring.
The study showed that composites may be utilised for commercial cars' leaf springs and still fulfil criteria while significantly reducing weight. In terms of weight, price, and strength, a comparison between composite and steel leaf springs has been done. When the analytical and FEA findings were compared, a fair level of agreement was found. Deflection in the composite leaf spring is 2.6 times lesser than conventional steel respectively, using the composite (E-Glass/Epoxy) leaf spring. The findings show that compared to a traditional steel spring with equivalent design criteria, the composite leaf spring is both lighter and more cost-effective.
GFRP with prosopis juliflora has maximum values in mechanical testing, S5 specimen has good values with high mechanical property.
GFRP density is less than steel and cfrp.

Gfrp (S5) has good thermal property compare to cfrp .

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