Diyala Journal of Engineering Sciences

Journal homepage: https://djes.info/index.php/djes

ISSN: 1999-8716 (Print); 2616-6909 (Online)

Experimental Analysis of Composite Materials Leaf Spring Used in Automotive

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ARTICLE INFO

Article history:
Received 20 June 2021
Accepted 17 October 2021

Keywords:
Tensile
Fatigue
Hardness
Hybrid leaf spring

ABSTRACT

Product modifications or replacement of old products with new and improved material items. Vehicle suspension systems are another area where these developments are carried out on a regular basis. More efforts are being made to improve the user's comfort. Appropriate combination of comfort riding attributes and economics in leaf spring production becomes an evident requirement. Many changes have been made to the suspension system throughout time in order to enhance it. Some of the most recent suspension system innovations include the invention of the parabolic leaf spring and the usage of composite materials for these springs. The implementation of composite materials by replacing steel in conventional leaf springs of a suspension system. Composite material having a lot of good properties like simple fabrication, low weight and low cost to performance. The purpose of this study is to investigate the structural properties of a hybrid leaf spring consisting of 95% Epoxy, 5% carbon, 5% glass fiber, and 5% hybrid carbon-glass fiber composite. The various specimens were produced using the manual layup method, specimen was subjected to tensile, fatigue and hardness tests, with all data reported. The experimental results showed an increase in tensile, fatigue life and hardness when the reinforcing fibers are applied. The best results of the mechanical test obtained when hybrid reinforcement was applied.

1. Introduction

Safeguard natural resources and energy, in the current circumstance, automotive manufacturers' primary focus has been on weight reduction and increased deflection. The traditional leaf spring has many defects, one of which is deflection. The deflection of the composite leaf spring is greater than that of the standard leaf spring. The vehicle's weight can be lowered by changing the composite leaf spring. Weight loss may be accomplished largely by the use of superior materials, design optimization, and improved manufacturing methods. The suspension leaf spring, which accounts for 10% to 20% of the un-sprung weight in vehicles, is one of the possible areas for weight reduction [1].

One of the major applications of spring use in the industry is the leaf spring. It is widely used as automotive suspension. The rear or back suspension is usually in the form of a simply supported semielliptical beam. Leaf springs are long and narrow plates attached to the frame of a trailer that rest above or below the trailer’s axle Figure 1. Show leaf spring. There are single leaf springs and multi leaf spring used based on the application required. It is designed for vertical loading [2].

A leaf spring, which is an automotive component, is used to absorb vibration by means of variations in the spring deflection so that the potential energy is stored in spring as strain

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DOI: 10.24237/djes.2021.14403

energy and then released slowly. Therefore, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. Fortunately, composites have these characteristics [3]. With the use of composite materials, it was possible to reduce the weight of the leaf spring while maintaining load carrying capability and stiffness. Since composite materials have a higher elastic strain energy storage capability and a higher strength-to-weight ratio than steel [4]. Many researchers studied the application of composite materials in leaf spring manufacturing.

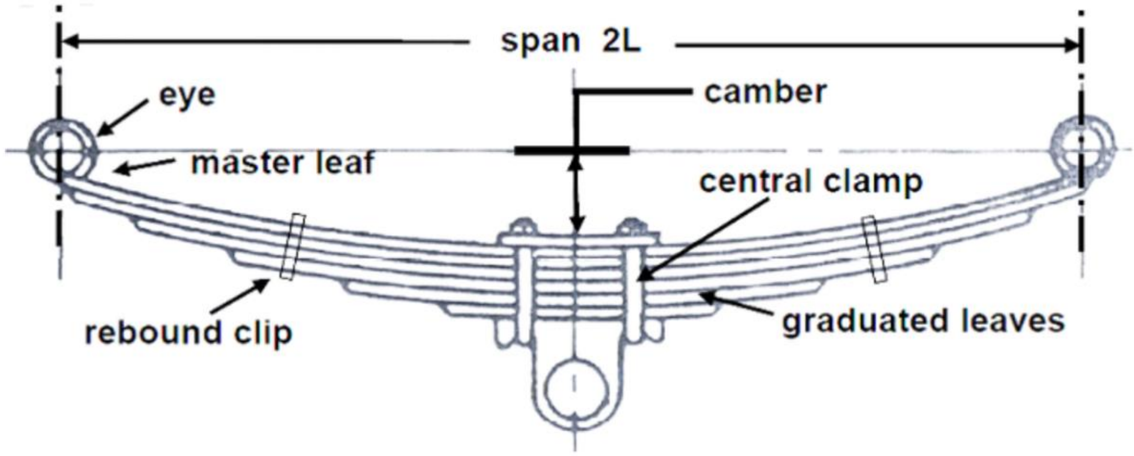


Figure 1. Leaf spring using in automotive

T.G. Loganathan et al. (2019), Studied the material replacement of the SAE 5160 steel to carbon reinforced polymer composite to increases the performance of the vehicle and to have a considerable strength, associated weight reduction with minimized fuel consumption. The research offers flexural, fatigue life, and damage caused outcomes for both theoretical and FE analysis. From this work it was seen that the deformation and weight of composite material less than of steel, the CFRP material offers more fatigue life than steel [5]. Amol Bhanage et al. (2014) Comparison the fatigue properties of SAE1045-450-QT steel and E - Glass/ Epoxy Composite material. A fatigue analysis is performed on an ANSYS Workbench v14.0 based on the available design data, and the simulation results are recorded. For the composite leaf spring, fatigue life. The fatigue life of an E - Glass Epoxy mono composite leaf spring is greater than that of an SAE1045 -450-QT multi leaf [6]. Mouleeswaran, et al. (2007), studied of static and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fiber reinforced polymer using life data analysis. Finite element analysis on 3-D model of composite multi leaf spring and steel is done using ANSYS 7.1 and the analytical results are compared with experimental results. Fatigue life of steel leaf spring and composite leaf is also predicted. Compared to steel spring, the composite leaf spring is found to have 64.95 % higher stiffness, 67.35 % lesser stress and 126.98 % higher natural frequency than that of existing steel leaf spring. A weight reduction of 68.15 % is also achieved by using composite leaf spring. It is also concluded that fatigue life of composite is more than that of conventional steel leaf spring [7]. M. M. Patunkar and D. R. Dolas (2011) FEA was used to model and analyze a composite leaf spring under static load conditions. For a better understanding, an investigation a commercial vehicle suspension system with leaf springs for modeling and analysis of stress, deflection, and weight reduction ratio using ANSYS 10.0 software. They compared the stress, deflection, and weight reduction ratio analysis results to the current analytical and experimental solutions. Furthermore, composites are roughly 40% lighter than traditional steel leaf springs [8]. Dev dutt Dwivedi and V.K.Jain. (2016) designed and studied of a composite leaf spring The analysis was carried out using ANSYS14.5. ANSYS's static structural tool was utilized. A three-layered composite leaf spring with a full-length leaf. The material utilized was an e-glass/epoxy combination. The results of conventional steel leaf springs were compared to the outcomes of composite leaf springs. In comparison to traditional steel leaf springs, E glass/epoxy material is stronger and lighter in weight. The results show that the deflection of a composite leaf spring for a given lower load, stress, deformation and lighter weight than steel leaf spring [9].

2. Aim of study

1. Reduce overall consumption and costs of fuel by decreasing suspension systems' weight.
2. Substitution of steel springs with composite leaf springs since composite leaf springs are introduced to improve safety, comfort and durability.
3. Fiber-reinforced polymers with a high damping factor can reduce noise, vibration, and ride harshness.
4. Composite materials have been developed Lower maintenance costs due to the absence of corrosion issues, as well as a favorable influence on production costs due to lower tooling costs.
5. Since composite materials leaf springs have a good corrosion resistance, a high strength to weight ratio, and a high elastic strain energy storage capacity, they are increasing the life of leaf springs.
6. Investigating the structural properties of a hybrid leaf spring composed of 95% Epoxy, 5% carbon, 5% glass fiber, and 5% hybrid carbon-glass fiber composite.
7. Demonstrating that hand layup is an advantageous process when used in manufacturing due to its advantages
8. Using mechanical experiments to assess the efficiency of the proposed composite leaf spring (Tensile, Fatigue life and Hardness).

3. Problem definition

The suspension leaf spring, which contributes for 10-20% of the us-sprung weight of a car, is one of the prospective components for weight reduction. The use of composite materials aids in the construction of a better suspension system with a better ride quality if it can be done without significantly increasing the cost and lowering the quality and dependability. The link between specific strain energy and spring design may be described as follows. Springs are designed to store energy before gently releasing it. The ability to store a greater quantity of strain energy guarantees that the suspension system is pleasant [10].

It is obvious that materials with lower modulus and density have a higher specific strain energy capacity. Because of the increased elastic strain energy storage capacity and high strength to weight ratio of composite materials, it was able to lower the weight of the leaf spring without sacrificing load bearing capacity or stiffness [11].

4. Composite materials

Leaf springs are generally made of plain carbon steel with a carbon content of 0.9 to 1%. The use of a specially designed composite leaf spring instead of a steel leaf spring due to their high strength-to-weight ratio, fatigue resistance, and natural frequency, composite materials are ideally suited for leaf spring applications. Internal damping in composite materials results in better vibration energy absorption inside the material, resulting in less vibration noise transmission to nearby structures [12, 13].

5. Experimental details

3.1 Materials used

The matrixes used is an epoxy, which is a thermosetting polymer with unique mechanical and resistance properties. Epoxy paste has a high degree of hardness and chemical resistance [14]. Furthermore, owing to the chemical structure of this resin, it has a high basic adhesion. In this study, carbon fiber and glass fiber are used as reinforcement. Carbon fiber has a low impact resistance, a high basic strength and modulus [15], a high fatigue strength, and a high price. Glass fiber is inexpensive, has excellent insulating properties, is dense, and has a low fatigue strength. Show the Figure (2) shows the materials are used in this study.

Epoxy (Cleaver) reinforced with (E-glass, carbon) hybrid fibers with the properties listed in Table 1. The reinforcement material is 5% for carbon, glass fiber and 2.5% for carbon and glass fiber from the total weight. Showed leaf spring materials with specified weight, and weight ratios ψ within a specific range and depending on the equation below [16]:

$$\psi = (W_f / W_c)\ 100\% \qquad (1)$$

$$W_c = W_f + W_m \qquad (2)$$

where: (W_f,W_m,W_c) represent the weight of fiber, matrix material and composite materials, respectively.

Table 1: The properties of Epoxy, Carbon fibers, E-glass fibers [15]

Type	Epoxy	Carbon fibers	E-glass fibers
Density	$1.1\frac{g}{cm^3}$	$1.5\frac{g}{cm^3}$	$2.5\ \frac{g}{cm^3}$
Tensile Strength	68Mpa	1830Mpa	3445Mpa
Modulus of Elasticity	2.9Gpa	142Gpa	76Gpa
Poisson's Ratio	0.3	o.27	0.27

Figure 2. Glass, Carbon fibers, Epoxy that use

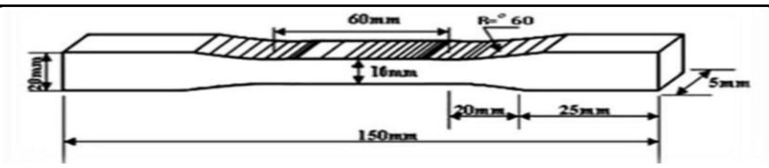
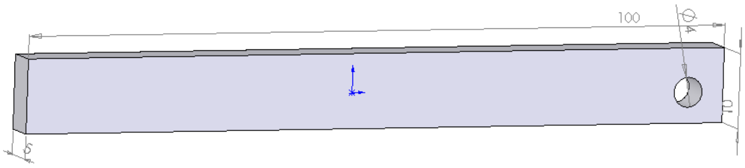
5.2 Preparation of the samples

The composite was prepared using hand lay-up molding. To ensure that the final composite sheet has the proper thickness and follows an acceptable bonding series. The reinforcing fibers are laid down layer by layer in the order specified. In a 3:1 ratio, epoxy resin is blended with hardener (1hardener and 3 Epoxy). Epoxy was applied to the fiber layers using a brush. The first layer was Epoxy, followed by a layer of glass or carbon or hybrid fibers positioned at the desired weight percent. Table (2) shows the reinforcement percentages. The composite sheets were left at room temperature for 24 hours to ensure maximum Epoxy curing. The sheet was then placed in the drying oven for 1 hour at (60 ºC) to eliminate the stresses and air bubbles that developed during the layering process. For the preparation of the test samples, the molded material was taken from the mold and cut in accordance with the ASTM standard. The standard dimensions of samples are shown in Table 3.

Table 2: Type of used samples

No. of samples	Content
A1	Epoxy + hardener
A2	A1 reinforced with 7 layers of carbon fibers
A3	A1 reinforced with 7 layers of glass fibers
A4	A1 reinforced with3 layers of glass and 4 layer of carbon fibers

Table 3: Samples dimensions and standard specifications for testing samples [16]

Test	Samples Dimension	Standared Specification
Tensile test		ASTM-D638
Fatigue test		HSM 20
Hardness test		ASTM-D2240

6. Mechanical test of composite material

6.1 Tensile test

A controlled electromechanical testing instrument was used to determine tensile strength. Loading the ASTM D638 samples to fracture under a continuous load of 30 kN at a speed of 5 mm/min and a span length of 50 mm [16]. Figure (3) shows the tensile test device. The device's top and lower jaws are used to deposit the sample. The force is applied to the sample; the device's top grip pulls the sample upward while the lower jaw secures the opposite end. The gadget displays a schematic of the stress-strain relationship as well as a diagram of the load-extension relationship and the stress strain curves were used to compute tensile strength and deformation. Figures (4) (5) show the samples before and after the test, the tensile strength is calculated from the following Eq. (3):

$$\sigma_t = \frac{p}{bh} \tag{3}$$

Figure 3. Tensile test device

Figure 4. Tensile samples

Figure 5. Tensile samples after testing

6.2 Fatigue test

Because the results of all of the samples' tests demonstrate that hybrid composite materials have the best properties, a sample of hybrid composite materials was selected out and put through with a fatigue test., an alternate bending fatigue machine manufactured by Hi-Tech was used. Figure (6) shows the machine. This machine's aim is to apply alternating or fluctuating bending to a cantilevered strip of material in order to calculate fatigue efficiency. If the cantilever rotates, a known bending moment is imposed, resulting in a sinusoid ally varying force. High speeds are feasible, allowing millions of cycles to be completed in hours. The disadvantage is that the only tension regime available is that of exact reverse. To address this problem, a new fatigue machine design was developed in which a cantilever could be deflected to apply varying bending stress in the cantilever. The free end of a cantilever is driven up and down by a reciprocating mechanism in such a machine. Big deflections may also be imposed, causing high stresses in nonmetallic materials with low Young's modulus values.

Figure 6. Alternating bending fatigue device

$$\sigma = \frac{6pl}{bt^2} \quad (5)$$

$$\delta = \frac{4pl^3}{Ebt^3} \quad (6)$$

$$l = \frac{1.5Et\delta}{\sigma} \quad (7)$$

where b is specimen width, t is specimen thickness, p is load applied, σ is applied Stress, E is young of modulus δ is free end deflection, L is initial cantilever length, l is cantilever length, Since the stress has been added.

Fatigue test sample are cut according to the HSM 20 standard dimension as shown the table 3. Figure 7. Show the fatigue test samples.

Figure 7. Fatigue test samples

6.3 Hardness test

Hardness testing was regarded as a quality control test since it enabled the assessment of a material's qualities and aided in the identification of the appropriate materials for the necessary purpose. Shore D testing with the indenter parameters indicated in. For all mixes and composites, the average of the three device readings was taken. Figure 8 shows Display the hardness devise.

Figure 8. Hardness test device

7. Results and discussion

7.1. Tensile result test

The experimental results in Figure 9. Demonstrate that adding carbon and glass fibers to Epoxy raises the tensile values to 184, 170, and 145 MPa for samples A4, A3, and A2. The biggest gain occurs when hybrid fiber reinforcement is used (combining the excellent properties of the two fiber). This is because Epoxy resin is a brittle substance with low tensile strength, but when reinforced with fibers, the tensile strength improves. Carbon and glass fibers have strong ultimate tensile strength and ductility, giving the Epoxy matrices strength and toughness.

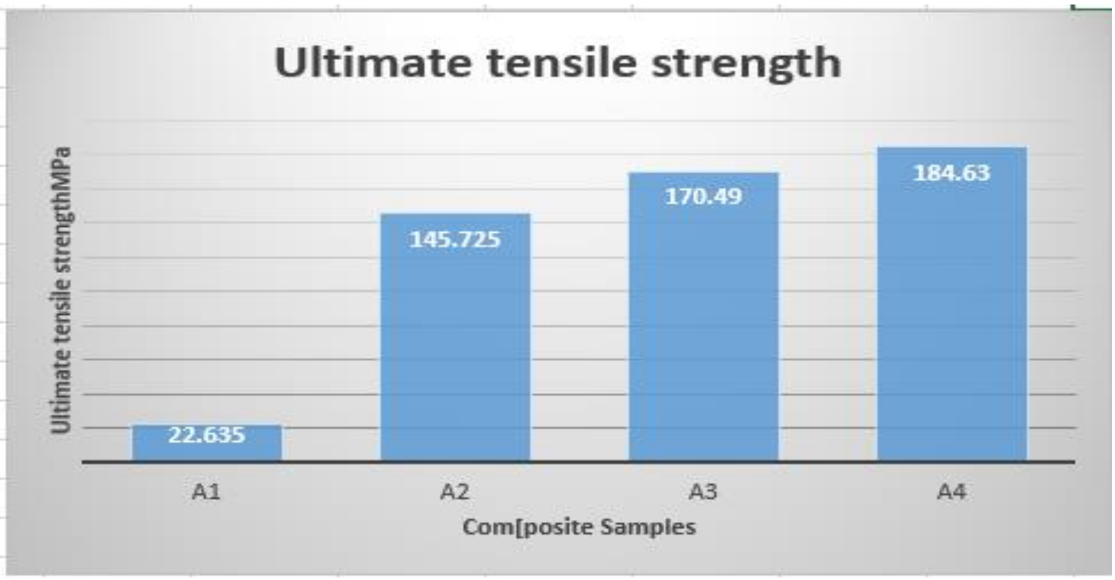


Figure 9. Ultimate tensile strength of composite materials

Figure 10. Show the modulus of elasticity of Epoxy before and after reinforced with Carbon fibers, Glass fibers and hybrid composite materials. The resistance to deformation under stress is defined as modulus of elasticity. It is defined by a material's rigidity. Because the fibers are made up of stiff chains aligned along the fiber axis, the modulus of elasticity increases from (2GPa) at A1 to (13GPa) at A2, A4, and finally to a maximum of (16GPa) at A3. This causes the fiber's stiffness to rise.

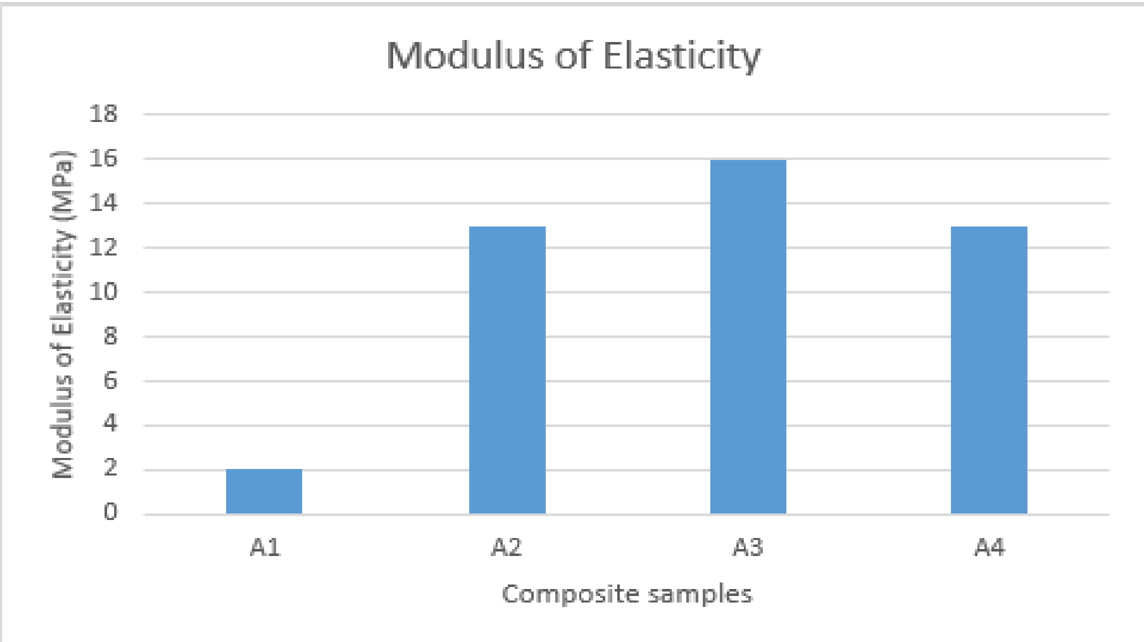


Figure 10. Modulus of elasticity of composite materials

Figure 11. Shows the relation between load and displacement developed in the samples. The sample A1 has less displacement while A3 has maximum displacement and carried high load because E-glass fiber has more ductility compared with Carbon fiber and Epoxy.

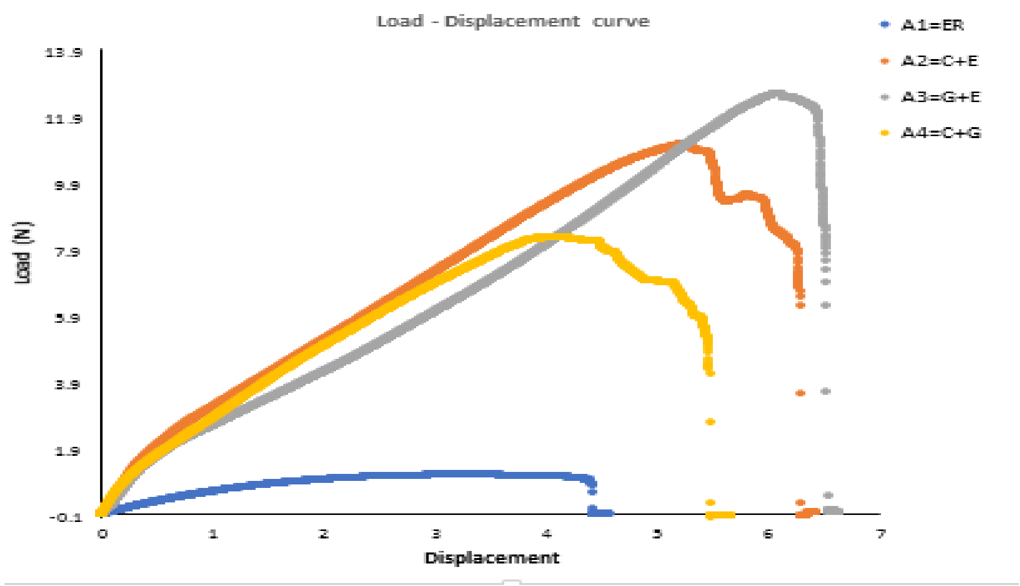


Figure 11. Load –displacement curve of composite materials

Figure 12. Shows the relation between stress-strain in the samples of composite materials. The tensile strength increases when reinforced with fibers. This is due to the fibers ability to carry the maximum part of the load in all hybrids composite compared with Epoxy.

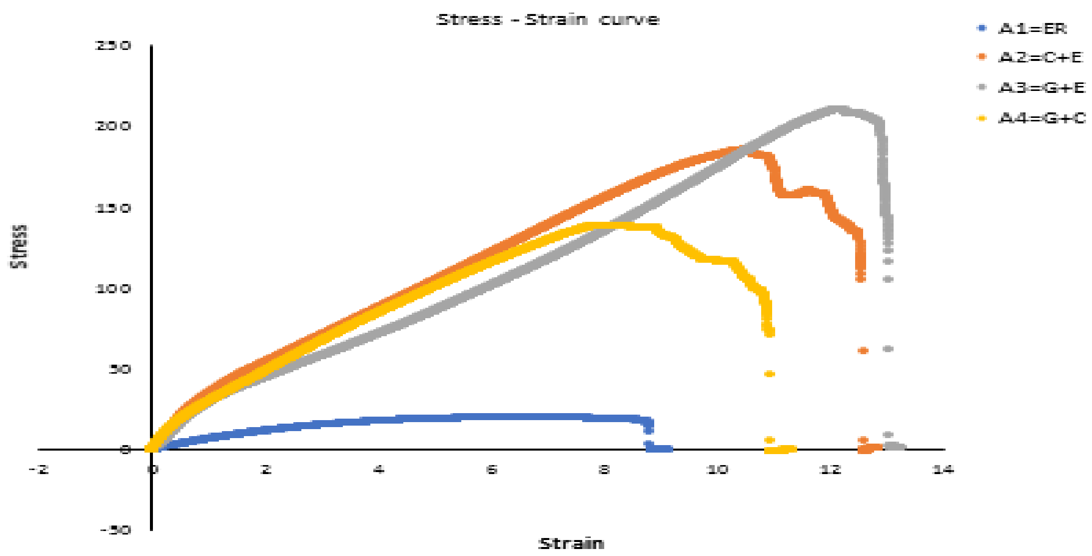


Figure 12. Stress-strain curve of composite materials

7.2 Fatigue result test

The sample (A4) consisting of (Epoxy reinforced with hybrid composite material) was chosen for the fatigue test because it has the best mechanical properties. Lab tests and findings reveal a decrease in fatigue cycles, even if the burden is increased on the test samples, as shown in the fatigue assessment table (4). Unknown fatigue limit is the A4 specimen (hybrid composite materials). Where they go with deflection (1x106) (2mm). If just the matrix and the enhanced fibers prevent splits from running toward the surface, hence only after (1x106) cycle, the samples were not split into two pieces. The S-N curve of hybrid composite materials is illustrated in Figure (13). In theory, glass, carbon fiber reinforced polymer composites should be fatigue resistant as long as the fibers bear the majority of the load and are not so extensible that significant elastic deformations of the matrix are allowed.

Table 4: Shows fatigue test details

Sample No.	Thickness (mm)	Load (N)	Length (mm)	Cyclic no. (N)
1	5	10	90	$1x10^6$
2	5	20	64	$1x10^6$
3	5	30	52	$1x10^6$
4	5	40	45	$8.5x10^5$
5	5	50	40	$6.3x10^5$
6	5	60	36	$5.3x10^5$

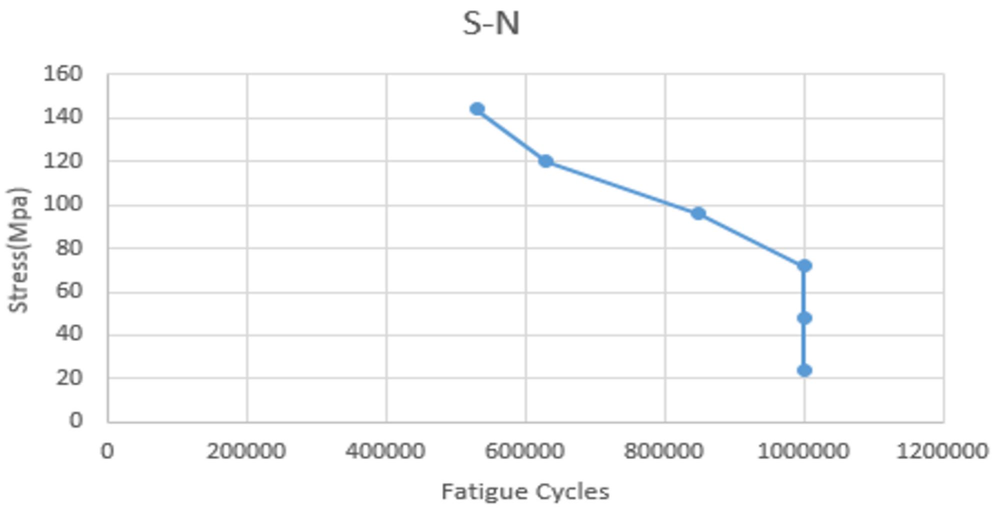


Figure 13. S-N curve of fatigue cycle of hybrid composite materials

7.3 Hardness result test

Figure (14) shows experimental results. Epoxy has a hardness value of 76.5Hv, which is then augmented by fiber after reinforcement. The improvement in durability around (84Hv, 82Hv, 85Hv) was applied to the fiber in the matrix, reducing the penetration rate on the composite material's surfaces and increasing the rigidity of the composite material. In addition, increased rigidity in the composites shows strong connections between the fibers and the matrix. E-glass/Epoxy composite mixes are the highest hardness value for carbon (A4).

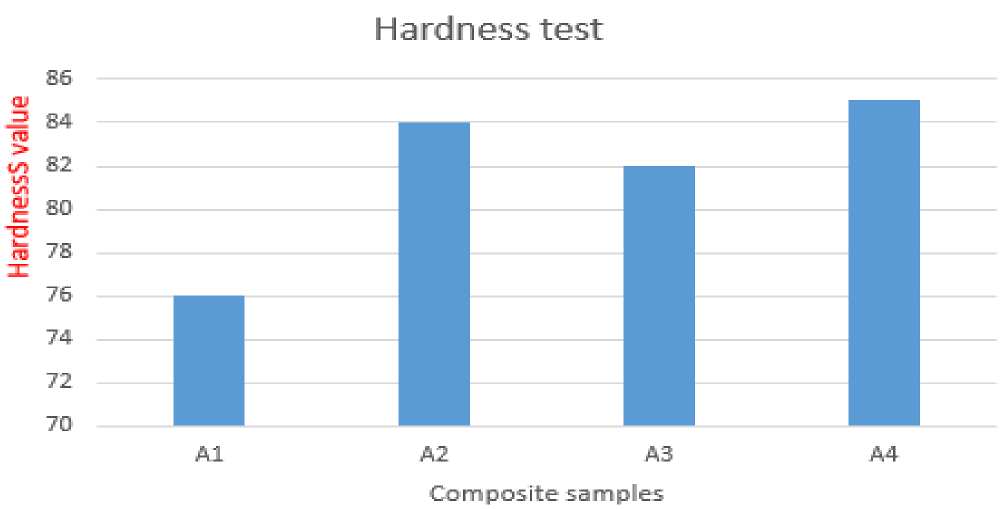


Figure 14. Hardness values of composite samples

8. Conclusions

The composite materials are ideal for the manufacture of leaf springs. The results demonstrate that hybrid composite materials have a high tensile strength value and that Epoxy reinforced with E-glass fiber has a high modulus of elasticity and a high displacement and strain. The fatigue life of hybrid composite materials is very long.

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