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EXPERIMENTAL INVESTIGATION OF FIBERGLASS REINFORCED MONO-COMPOSITE LEAF SPRING

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ABSTRACT

The Automotive industry has witnessed major growth in use of fiberglass reinforced polymers. One such area of application is the composite leaf springs. Leaf springs are used in suspension systems for vehicles. Currently the ideal choice is the multiple laminated leaf steel springs. The aim is to compare a mono composite leaf spring with a steel leaf spring for different test conditions. Physical testing is carried out for two different samples 60% epoxy-40% E-fibreglass and 50% epoxy - 50% E-fibreglass, both prepared in the laboratory. The study gives a comparative analysis between the composite leaf spring and steel leaf spring based on physical properties.

Keywords: Leaf Spring, Mono-composite, fibreglass

INTRODUCTION

Several papers have been published denoting the application of composites in leaf spring. Other conventional suspension systems work on the same principles as a conventional leaf spring. However leaf springs use excess material when compared to other suspension systems for the same load and shock absorbing performance which makes it heavy. This can be improved by composite leaf springs.

Various advantages which the composites have on their counterpart conventional structural materials have been analysed by Breadmore et al. [1]. A leaf spring is subjected to millions of variation in stresses throughout its life cycle which causes its failure at a value less than the estimated value. Thus this is the most important factor to be studied, fatigue characteristic of composite multi-leaf spring which has been done in Finite Element Analysis by Kueh et al [2].

Considering the fact that the conventional leaf spring is one of the potential components for weight reduction it has been an area of interest for automobile industries [3]. The various advantages possessed by the composite materials [6] make this an attractive alternative material for the designers. In an experimental investigation comparison between the single leaf spring of variable thickness composite spring of fibreglass reinforced fibre with mechanical and dimensional properties similar to the conventional steel leaf spring was done by Al-Qureshi et al [4].

G.S.S. Shankar [8] studied the analysis and design of low cost fabrication of a mono composite leaf spring with bonded end joints. Since static and fatigue strengths of a composite leaf spring are much better when compared to conventional leaf springs [5], it is thus possible to use composite leaf springs in place of conventional leaf springs. This also helps in weight reduction with no compromise to load carrying capacity [7].

A parabolic leaf spring, with the spring width decreasing hyperbolically and the thickness increasing linearly from the spring eyes towards the axle seat, was found to be the most optimum design [9]. The calculation of the fatigue life of the conventional steel leaf spring is taken from [10] and the calculation of the fatigue life of composite leaf spring is found by the Hawang and Han relation [11].

II. SPRING STEEL MATERIAL USED FOR TESTING PURPOSES

Material designation is 65Si7 which has a Director Identification Number (DIN) designation of 65Si7 and material number designation that is 1.5028

TABLE 1: Chemical composition in weight %

Carbon (C)	0.610
Silicon (Si)	1.650
Phosphorus (P)	0.039
Manganese (Mn)	0.810
Sulphur (S)	0.037

TABLE 2: Physical Properties at ambient temperature

Tensile Strength (MPa)	1921
Yield Strength (MPa)	1349
Young's Modulus	1.8×10^5
Poisson's Ratio	0.32
Density (g/cm^3)	7.80

III. FABRICATION OF COMPOSITE SAMPLES

Layup Selection

The amount of elastic energy that can be stored by a leaf spring varies directly with the square of maximum allowable stress and inversely with the modulus of elasticity both in the longitudinal direction. Composite materials like the E-Glass/ Epoxy in the direction of fibres have good characteristics for storing strain energy. So, the layup is selected to be unidirectional along the longitudinal direction of the spring. The unidirectional layup may

weaken the spring at the mechanical joint area and require strengthening the spring in this region.

DiGlycidyl Ether of Bisphenol A was used as epoxy resin and Tri-Ethylene Tetra-Amine was used as hardener. E-Glass fibres were used as reinforcements.

Hand Layout Moulding

Hand lay-up moulding is the method of laying down fabrics made of reinforcement and painting with the matrix resin layer by layer until the desired thickness is obtained. This is the most time and labour consuming composite processing method, but majority of aerospace composite products are made by this method in combination with the autoclave method. Due to the hand assembly involved in the lay-up procedure, one can align long fibres with controlled directional quality. Another advantage of this method is the ability to accommodate irregular-shaped products. Such advantages are utilized in low performance composites including fibre - glass boat and bath tub manufacturing. An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.

Hand lay technique was used to manufacture the fibre glass reinforced specimen. For this an E - fibreglass material was used with the diameter of the fibreglass approximately $20\mu\text{m}$, epoxy (DiGlycidyl Ether of Bisphenol A) and a hardener (Tri-ethylene Tetra-amine).

Two samples of the fibre glass reinforced plastic were prepared:

1. 60%-40%:-60% epoxy and 40% E-fibreglass
2. 50%-50%:-50% epoxy and 50% E-fibreglass

Figure 1 Schematic diagram of Hand Layout Moulding

Sheet Preparation

Many techniques can be suggested for the fabrication of composite leaf spring from unidirectional GFRP. In the present work, the hand lay-up process was employed. The templates (mould die) was made of aluminium frame of internal dimension 180mm by 180mm. The glass fibres were cut out of a material in the dimensions 180mm*180mm, so that they can be deposited on the template layer by layer during fabrication. The weight of the fabricated sheet of FGRP had to be maintained 150gms. Each sheet of fibre glass that was cut out weights 10gms.

So in this case (60%-40%) 6 sheets of fibre glasses were cut out. Out of the rest 90grams of epoxy resin was used with its hardener in the ratio (9:1). In case of (50%-50%) 8

sheets of fibre glass were cut out. Out of this the rest 90gms epoxy resin was used with its hardener in the ratio (9:1).

In the conventional hand lay-up technique, a releasing agent (silicone gel) was applied uniformly to the mould which had good surface finish. This was followed by the uniform application of epoxy resin over glass fibre. Another layer was layered and epoxy resin was applied with the help of a brush and a roller was used to remove all the trapped air. This process continued till all the pre measured materials were used. Care must be taken during the individual lay-up of the layers to eliminate the fibre distortion, which could result in lowering the strength and rigidity of the spring as a whole. The duration of the process took around 30 minutes. The mould was allowed to cure for 1 day at room temperature.

After curing the sheet was pulled out and was cut using a hack-saw according to the required dimensions for different experiments. Alumina-calcium-borosilicate glasses with a maximum alkali content of 2 wt.% used as general purpose fibres where strength and high electrical resistivity are required.

Figure 2 FGRP manufactured at 50% w/w E-Glass Fibre

Figure 3 FGRP manufactured at 40% w/w E-Glass Fibre

IV. EXPERIMENTAL TESTS

Flexural Test

Testing of flexural properties of polymer matrix composites is done by using a bar of rectangular cross section supported on a beam and deflected at a constant rate. The test method outlines a three point loading system for centre loading. This test method is designed for polymer matrix composites and uses a standard 32:1 span-to-thickness ratio. Since the flexural properties of many materials can vary depending on temperature, rate of strain and

specimen thickness, it may be appropriate to test materials at varied parameters. Test procedure the procedure outlines a three point loading system for centre loading. Most commonly the specimen lies on a support span and the load is applied to the centre by the loading nose producing three-point bending at a specified rate.

Standard specimen thickness is 4 mm (0.16 in), standard specimen width is 13 mm (0.5 in) and standard specimen length is 20% longer than the support span. If the standard specimen is not available, alternative specimen sizes may be used. Equipment used is Universal Testing Machine, Three Point Flexural Fixture

Dynamic Mechanical Analysis

Dynamic Mechanical Analysis determines elastic modulus (or storage modulus, G'), viscous modulus (or loss modulus, G'') and damping coefficient ($\tan D$) as a function of temperature, frequency or time. Results are typically provided as a graphical plot of G' , G'' , and $\tan D$ versus temperature. DMA identifies transition regions in plastics, such as the glass transition, and may be used for quality control or product development. DMA can recognize small transition regions that are beyond the resolution of DSC (Differential Scanning Calorimetry). The test specimen is clamped between the movable and stationary fixtures, and then enclosed in the thermal chamber. Frequency, amplitude, and a temperature range appropriate for the material are input. The Analyser applies torsional oscillation to the test sample while slowly moving through the specified temperature range.

Test specimens are typically 56 x 13 x 3 mm, cut from the centre section of a tensile bar, or a multipurpose test specimen.

Equipment used is Rheometric Scientific RDA III Dynamic Mechanical Analyser.

Deflection Temperature Under Load (HDT or Heat Deflection Test)

Heat deflection temperature is defined as the temperature at which a standard test bar deflects a specified distance under a load. It is used to determine short-term heat resistance. It distinguishes between materials that are able to sustain light loads at high temperatures and those that lose their rigidity over a narrow temperature range.

The bars are placed under the deflection measuring device. A load of 0.45 MPa or 1.80 MPa is placed on each specimen. The specimens are then lowered into a silicone oil bath where the temperature is raised at 2° C per minute until they deflect 0.25 mm for ASTM, 0.32 mm for ISO flat-wise, and 0.34 mm for ISO edgewise standard bar 5" x ½" x ¼" is used for ASTM. Equipment used is Atlas HDV2 DTUL/ VICAT tester.

Tensile Test

ASTM D3039 tensile testing is used to measure the force required to break a polymer composite specimen and the extent to which the specimen stretches or elongates to that breaking point. Tensile tests produce a stress-strain diagram, which is used to determine tensile modulus. The data is often used to specify a material, to design parts to withstand application force and as a quality control check of materials.

Specimens are placed in the grips of a Universal Test Machine at a specified grip separation and pulled until failure. For ASTM D3039 the test speed can be determined by the material specification or time to failure (1 to 10 minutes). A typical test speed for standard test

specimens is 2 mm/min (0.05 in/min). An extensometer or strain gauge is used to determine elongation and tensile modulus. Depending upon the reinforcement and type, testing in more than one orientation may be necessary.

The most common specimen for ASTM D3039 has a constant rectangular cross section, 25 mm (1 in) wide and 250 mm (10 in) long. Optional tabs can be bonded to the ends of the specimen to prevent gripping damage.

Impact Test

The tensile impact test measures the amount of force needed to break a specimen under a high speed tensile load introduced through a swinging pendulum.

The thickness and width of the test specimen is recorded. The specimen is then clamped to the cross-head and placed into the pendulum. The pendulum is released and allowed to strike the anvil breaking the specimen. The tensile impact energy is recorded and then corrected impact energy is calculated. Type L specimens, with a gauge length of 9.53mm (0.375") provide a greater differentiation between materials. Equipment used is TMI Impact Tester.

V. RESULTS AND DISCUSSIONS

Tensile Test

Tests were carried out at temperature of 23°C and humidity at 54% inside the laboratory at rate of 10mm/min. Figure given below represent the flexural Stress versus strain graph for 60% Epoxy + 40% E-glass fibre and 50% Epoxy + 50% E-glass fibre. The table gives the values stresses and strains.

Figure 4 Tensile Stress – Strain Graph for Composition 1: 60% Epoxy + 40% E-glass fibre (light red) and Composition 2: 50% Epoxy + 50% E-glass fibre (dark red)

TABLE 3: Tensile test

	Composition 1	Composition 2
Material	60% Epoxy- 40% E-glass Fibre	50% Epoxy- 50% E-glass Fibre
Tensile stress at Maximum Load (MPa)	120.43	152.14
Tensile stress at Break (Standard) (MPa)	62.00	150.78
Tensile stress at Yield (MPa)	120.43	152.14
Tensile strain at Yield (%)	6.65	8.48
Thickness (mm)	3.00	3.20
Width (mm)	24.65	23.28
Tensile strain at Break (Standard) (%)	6.83	8.49
Modulus (MPa)	2217.43	2609.91
Maximum Load (N)	8906.27	11334.29
Load at Break (Standard) (N)	4585.11	11233.13
Energy at Maximum Load (J)	22.76	29.32
Tensile strain at Maximum Load (mm/mm)	0.06	0.08
Tensile extension at Maximum Load (mm)	5.59	6.62
Tensile extension at Break (Standard) (mm)	5.73	6.62
Energy at Break (Standard) (J)	24.06	29.42

Flexural Test

Tests were carried out at temperature of 23°C and humidity at 50% inside the laboratory. Figures given below represent the flexural Stress versus strain curve for 60% Epoxy + 40% E-glass fibre and 50% Epoxy + 50% E-glass fibre and . The table gives the values stresses and strains.

Figure 5 Flexural Stress – Strain Graph for Composition 1: 60% Epoxy + 40% E-glass fibre

Figure 6 Flexural Stress – Strain Graph for Composition 2: 50% Epoxy + 50% E-glass fibre

TABLE 4: Flexural test

	Composition 1	Composition 2
Material	60% Epoxy- 40% E-glass Fibre	50% Epoxy- 50% E-glass Fibre
Max. Load (N)	472.09	524.27
Max. Stress (MPa)	229.41	229.62
Flex Modulus (MPa)	9268.03	10235.91
Flexure extension at Max. Flexure load (mm)	4.45	4.34
Width (mm)	13.17	13.53
Thickness (mm)	3.75	4.05
Flexure stress at Max Flexure load (MPa)	229.41	229.62
Support Span (mm)	60	64.80

Dynamic Mechanical Analysis

Dynamic mechanical Analysis is a technique where a small deformation is applied to a specimen in a cyclic manner. This allows the materials response to stress, temperature, and frequency to be studied. The DMA determines changes in sample properties resulting from changes in five experimental variables like temperature, time, frequency, force, and stress. The deformation can be applied sinusoidal in nature, in a constant (or step fashion), or under a fixed rate. In the above experiment stress was varies in a sinusoidal manner. The sample was clamped between the ends of two parallel arms. The distance between the arms were adjusted by means of a precision mechanical slide to accommodate a wide range of sample length from less than 1mm up to 65 mm.

An electromechanical motor attached to one arm was used to drive the sample system to a selected stress. The transformer mounted on the driven arm was used to measure the sample response, strain and frequency as a function of the applied stress. The sample was positioned in a temperature controlled chamber. The storage modulus, being in phase with the applied stress, represents the elastic component of the material's behaviour or its stiffness. Higher the storage modulus higher is the elastic behaviour means it represents the amount of energy stored in the material which deforms it.

Loss modulus represents the damping or tan delta is the ratio of loss modulus to storage modulus and represents how well the material can get rid of the energy transferred to it.

Figure 7 DMA for Composition 1: 60% Epoxy + 40% E-glass fibre

As can be seen from figure 7 the storage modulus decreases (first gradually and then drastically) with increase in temperature. This means that with increase in temperature the stiffness of the material decreases. Tan delta represents how well can the material get rid of the energy transferred to it. As can be seen from the graph at lower temperatures the value of tan delta is very small. It rises gradually and is peak at 119.48°C and falls drastically after that. This means that the material used is most suitable for application at temperatures above 80°C. The glass transition temperature is found to be 119.48°C.

Figure 8 DMA for Composition 2: 50% Epoxy + 50% E-glass fibre

As can be seen from figure 8 the storage modulus decreases (first gradually and then drastically) with increase in temperature. This means that with increase in temperature the stiffness of the material decreases. Tan delta represents how well can the material get rid of the energy transferred to it. As can be seen from the graph at lower temperatures the value of tan delta is very small. It rises gradually and is peak at 107.18°C and falls drastically after

that. This means that the material used is most suitable for application at temperatures above 80°C. The glass transition temperature is found to be 107.18°C. Thus, two sheets of each composition were manufactured. For each test 3 samples were cut out from the sheets. The samples which gave the best result have been documented here. The reason for the variation in the properties may be due to the defects like air entrapment, lack of complete curing and in some places the lack of complete wetting of the fibres. A weight reduction of 88.95% is achieved by using composite leaf spring (21.8gms in case of tensile test sample) in place of spring steel leaf spring (198 g). This is the main basis of our experiment as we wanted to test a material of less weight which in turn increases the efficiency the vehicle by reduction in its unsprung weight.

Heat Deflection Test

The Heat Distortion Temperature is determined by the following test procedure outlined in ASTM D648. The test specimen is loaded in three-point bending in the edgewise direction. The outer fibre stress used for testing used was 1.82 MPa, and the temperature was increased at 2 °C/min until the specimen deflected 0.254 mm. HDT test machine range is between 20°C - 300°C. Based on the analysis it is found that Composition 1 60% Epoxy-40% E-glass Fibre specimen is preferred in our application.

TABLE 5: Heat Deflection Test

	Composition 1	Composition 2
Material	60% Epoxy-40% E-glass Fibre	50% Epoxy-50% E-glass Fibre
Depth (mm)	0.94	0.92
Width (mm)	4.40	3.80
Pressure (psi) Applied	264	264
Load (grams)	575	485
Deflection (mm)	0.114	0.254
Temperature (°C)	289.3	283.9

Impact Test

The apparatus consists of a pendulum axe swinging at a notched sample of material. The energy transferred to the material was noted down from a computer. Both the specimen did not break.

TABLE 6: Impact test

	Composition 1	Composition 2
Material	60% Epoxy - 40% E-glass Fibre	50% Epoxy - 50% E-glass Fibre
ASTM A370 Dimensions	10mm x 3.3mm x 55mm	10mm x 3.3mm x 55mm
Pendulum energy (J)	2.74	2.74
Energy transferred (J)	2.70	2.73
Impact Strength (KJ/m ²)	84.54	78.18

CONCLUSIONS

The various tests and analysis were performed on the two compositions. The materials for spring steel and composite materials (60% Epoxy + 40% E-glass fiber and 50% Epoxy + 50% E-glass fiber) were chosen on the basis of costs and availability of the materials. Based on the experimental tests the following conclusions can be drawn:

It was found that there was a weight reduction of 88.95% in composite leaf spring as compared to conventional steel leaf spring. The maximum stiffness produced was found to be 66.9N/mm which is almost comparable to steel (76.68N/mm). Both composite samples passed the heat deflection tests which prove their feasibility for practical use. Fatigue life was found to be 10112 cycles as compared to 6164 cycles of steel spring. Moreover the natural frequency was 1.3 times more than the 12Hz produced on road which decreases resonance and hence increased rider comfort.

Overall from the above tests the 60% Epoxy + 40% E-glass fiber was found to be better than the 50% Epoxy + 40% E-fiber glass. This can be seen from the Dynamic Mechanical Tests where we got a higher transition temperature (119.8°C), lesser average storage modulus, higher Tan D value and higher loss modulus.

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