FABRICATION AND EXPERIMENTAL ANALYSIS OF CARBON FIBRE/EPOXY COMPOSITE LEAF SPRING

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Abstract
Leaf spring is one of the main components and it provides a good suspension. It plays a vital role in automobile sector. A suspension system of vehicle is also an area where these innovations are carried out regularly. Leaf springs are one of the oldest suspension components that are being still used widely in automobiles. Weight reduction is also given due to importance by automobile manufacturers. The automobile sector has shown increased interest in the use of composite leaf spring in the place of conventional steel leaf spring due to its high strength to weight ratio. This work deals with replacement of conventional steel leaf spring of a heavy duty vehicle with composite leaf spring using Carbon Fiber/Epoxy. Dimensions of the composite leaf spring are to be taken as same dimensions of the conventional leaf spring. The objective is to compare the load carrying capacity, stresses, deflection and weight savings of composite
Key words: Carbon Fiber/Epoxy.

I INTRODUCTION

1.1 Definition of Composite Material:

The word composite in the term composite material signifies that two or more materials are combined on a macroscopic scale to form a useful third material. The key is the macroscopic examination of a material where in the components can be identified by the naked eye. Different materials can be combined on a microscopic scale, such as in alloying of metals, but the resulting material is, for all practical purposes macroscopically homogeneous, i.e., the components cannot be distinguished by the naked eye and essentially act together. The advantage of composite material is that, if will designed, they usually exhibit the best qualities of their components or constituents and often some qualities that neither constituent possesses.

Some of the properties that can be improved by forming a composite material are:

- Strength
- Stiffness
- Corrosion resistance
- Wear resistance
- Attractiveness
- Weight
- Temperature-dependent behaviour
- Thermal insulation
- Thermal conductivity
- Acoustical insulation

Naturally, not all of these properties improved at the same time nor is there usually any requirement to do so. In fact, some of the properties are in conflict with one another, e.g., thermal insulation versus thermal conductivity. The objective is merely to create a material that has only the characteristics needed to perform the design task.

1.2 Fibers:

Materials in fiber form are stronger and stiffer than that used in a bulk form. There is a likely presence of flaws in bulk material which affects its strength while internal flaws are mostly absent in case of fibers. Further, fibers have strong molecular or crystallographic alignment and are in the shape of very small crystals. Fibers have also low density which is advantageous.

A fabric is constructed of interlaced yarns, fibers or filaments. Typical glass- fibers fabrics are manufactured by interlacing warp (length wise) yarns and fill (cross wise) yarns on conventional weaving looms. By the weave patterns are plain, twill, leno and unidirectional.

Plain weave is the oldest and most common textile weave. In this, one warp end is woven over one fill yarn and under the next and the process is repeated.
Two types of glass fibers are used in FRP industries. They are

- E-glass
- S-glass

Both are having lowest cost among all commercial fibers.
S-glass has high tensile strength. It's typical composition is 65% SiO_2, 25% Al_2O_3 and 10% MgO. The cost of S-glass is 20-30 times that of E-glass. The tensile strength of S-glass is 33% greater and the modulus of elasticity is 20% higher than that of E-glass.
Clothing materials. Modern advances have been made in a number of directions which include the following.

- Multi-dimensional weaving
- 3-D weaving to provide greater transverse strength
- Crimp less weaves with secondary yarns knitted to hold together collimated straight primary yarns in one or more unidirectional plies.

These advanced are mainly related to carbon fibers.

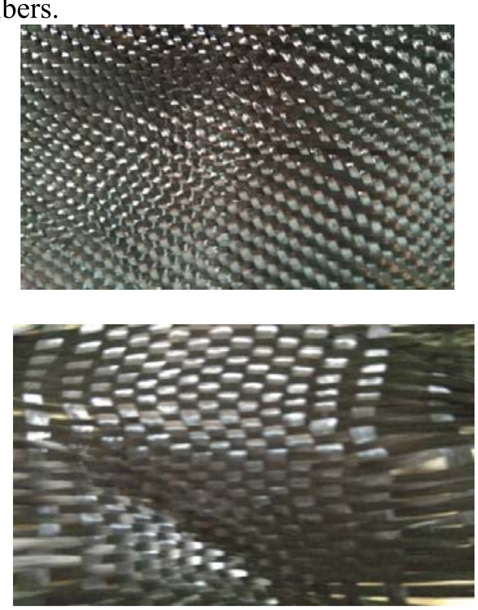


Fig (1.1): Carbon Fiber

1.3 Epoxy resins
Epoxy resins are mostly used in aerospace structures for high performance applications. It is also used in marine structures, rarely tough, as cheaper varieties of resins other than epoxy are available. The extensive use of epoxy resins in industry is due to:

- The ease with which it can be processed,
- Excellent mechanical properties in composites and
- High hot and wet strength properties (150^0C).

Performance of epoxies is superior to polyester resins due to their superior mechanical properties and better resistance to degradation by water and other solvents. The chemistry of the epoxy resin components is such that it gives a better adhesion to reinforcing fiber than polyester resins.

Fig(1.2): Epoxy resin

1.4 Vinyl ester resins
Being a combination of the principles of both epoxy and polyester resin chemistry, vinyl ester resins have a close resemblance to polyester resins, but have a chemical similarity to epoxy resins. Vinyl ester resin is superior to polyester resin because it offers a great resistance to water. These resins provide superior chemical resistance and superior retention properties of strength and stiffness at elevated temperature.

II FABRICATION PROCESS

There are many different fabrication process in the in the composite materials. The following are the some of different types of fabrication process in composite materials.
2.1 Types of fabrications process in the composite materials

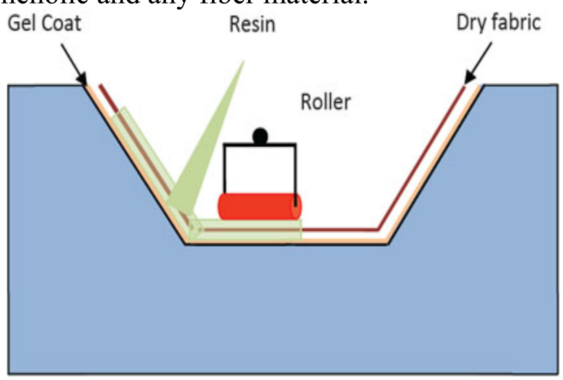
- Wet/Hand Lay-Up
- Spray Lay-Up

2.1.1 Wet/Hand Lay-up

- The fibers are first put in place in the mould.
- The fibers can be in the form of woven, knitted, stitched or bonded fabrics.
- Then the resin is impregnated.

- The impregnation helps in forcing the resin inside the fabric.
- The laminates fabricated by this process are then cured under standard atmospheric conditions.

The materials that can be used have, in general, no restrictions. One can use combination of resins like epoxy, polyester, vinyl ester, phenolic and any fiber material.



Fig(2.1.1): Wet or hand lay-up fabrication

2.1.2 Spray Lay-Up

Fiber is chopped in a hand-held gun and fed into a spray of catalyzed resin directed at the mould. The deposited materials are left to cure under standard atmospheric conditions. The fabrication method is depicted in the below Figure.

The polyester resins can be used with glass roving's is best suited for this process.

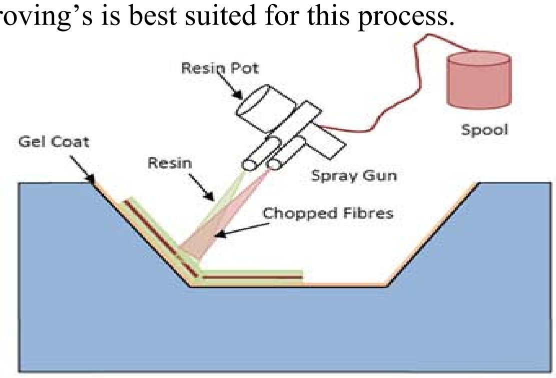


Fig (2.1.2): Wet or hand spray lay-up fabrication

III INTRODUCTION OF LEAF SPRING

3.1 Leaf Springs

Originally called laminated or carriage spring, a leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. It is also one of the oldest forms of springing, dating back to medieval times.

The advantage of leaf spring over helical spring is that the end of the springs may be guided along a definite path.

Fig(3.1): Leaf Spring

How Leaf Springs Work

Before you start your towing trip, it's a good idea to go over a brief checklist -- for safety's sake. You take a good look in your mirrors, adjusting them correctly in order to see passing traffic on the road. You've chosen the correct hitch and connected the towing vehicle to the trailer properly. The brake lights and braking systems are working synchronously, assuring you of the ride's legality. With everything loaded up, you're pretty confident the truck is ready for the job, so you head out on the road toward your destination. Once you reach a steady speed, however, the trailer behind your truck starts to bounce and sway a little more than it should. Pulling over to the side of the road, you rack your brains to figure out what you missed. You start to wonder if your cargo weight is maybe too high -- but what can you do about it?

3.3 Manufacturing of Composite Leaf Spring by Hand Lay-Up Operation Compositions

Composites are composed of

- **Resins -** The primary functions of the resin are to transfer stress between the reinforcing fibers, act as a glue to hold the fibers together, and protect the fibers from mechanical and environmental damage. The most common resins used in the production of FRP grating are polyesters (including orthophthalic-"ortho" and isopthalic-"iso"), vinyl esters and phenolics.
- **Reinforcements -** The primary function of fibers or reinforcements is to carry load along the length of the fiber to provide strength and stiffness in one direction. Reinforcements can be oriented to provide tailored properties in the direction of the

loads imparted on the end product. The largest volume reinforcement is glass fiber.

- **Fillers** - Fillers are used to improve performance and reduce the cost of a composite by lowering compound cost of the significantly more expensive resin and imparting benefits as shrinkage control, surface smoothness, and crack resistance.
- **Additives** - Additives and modifier ingredients expand the usefulness of polymers, enhance their process ability or extend product durability

Each of these constituent materials or ingredients plays an important role in the processing and final performance of the end product.

3.3.1 Procedure

Step -1: Clean the surface with a neat cloth to remove the dust particles present.

Fig(3.3.1(a)): Leaf spring arrangement

Step- 2: Apply PVC on the cleaned surface so that the removal of object will be easy.

Step-3: Preparation of resin. Take equal parts of resin and binder then mix them to make the solution at atmospheric temperature only.

Fig(3.3.2(b)): Resin preparation

Step-4: Take a layer of coir in a specified shape.

Step-5: Place the carbon fiber of one layer on the PVC coated surface.

Step-6: Apply the resin on the carbon fiber.

Fig(3.3.3(c)): Applying resin on carbon fiber

Step-7: Arrange one-by-one in parallel direction and place one layer over another layer.

Similarly apply resin to the layers as above mentioned.

Step-8: Place the lamina in open atmosphere to dry.

3.4 Fabricated Samples

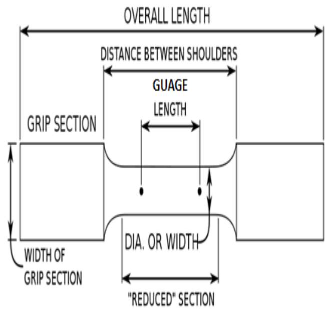
Fig (3.4.): Fabricated samples

3.5 Mechanical Testing

After fabrication the test specimens were subjected to various mechanical tests as per ASTM standards. The tensile test and impact tests of composites were carried out. The tensile test is generally performed on flat specimens. A uni axial load is applied through both the ends. The ASTM standard test method for tensile properties of fiber resin composites has the designation D 3039-76.

Low velocity instrumented impact tests are carried out on composite specimens. The tests are done as per ASTM D 256 using an impact tester. The charpy impact testing machine has been used for measuring impact strength.

3.5.1Specimens before Testing



Fig(3.5.1): Specimen Setting

IV EXPERIMENTATION AND RESULTS

4.1 Theory

In any design work, it is important to consider practically realizable values of strength of the materials used in design. The tension test is one of the basic tests to determine these practical values. The other tests being impact test, endurance or fatigue test, compression test, hardness test.The tests are conducted on specimen prepared out of randomly selected materials from the supplier's lot and therefore they also act as a quality test for acceptance of the material by the buyer.

The range of values obtained from the tests forms the basis for the size of the material in the products for the factor of safety. The tension test is conducted on a universal testing machine at room temperature. It is carried out by stretching a standard specimen is subjected to a gradually applied tensile load with the help of hydraulic system and the load is measured by a pendulum dynamometer.

The stretch undergone by the specimen is measured by an elongation scale with a least count of 1 mm fixed to the loading unit for every increment in the load. The simple stress and strain developed in gauge length portion is calculated using the formulae.

Stress (**σ)** = Load/ Original cross sectional area

Strain (**e**) = Increment in length / original gauge length

Tensile test is conducted by gripping the tests specimen between the upper and middle crosshead.

4.2 Procedure

1. Measure the original gauge diameter (d) and gauge length of the specimen by means of a vernier caliper& steel rule respectively. Mark gauge length by two tiny dots using a dot punch.
2. Grip the test specimen vertically and firmly between the upper crosshead jaws of the UTM by operating the hard wheels provided on the above two crossheads.
3. Adjust the machine to read zero on the elongation scale by opening the left control valve and closing the right control valve.
4. Select the load measuring range according to the capacity of the test piece by operating the load selector knob present on the right side of the control panel. If the test specimen is composite material and choose the suitable load range.
5. Fix the pen in the pen holder of the load elongation recording system.
6. Adjust the load indicating pointer (black needle) and dummy pointer (red pointer) to zero position in the dial of the control panel before conducting the actual test.
7. Now close both the left control valve and right control valve completely.
8. To apply the load on the specimen press the pump " on " button existing on the control panel and then immediately start opening right control valve gradually. While opening the right control valve, the left control valve should be completely closed the load will not be applied on the specimen.
9. Increase the load on the specimen gradually at equal intervals opening the right valve and then record the corresponding increase in length of the specimen from the elongation scale provided at the load elongation recording system.
10. Continue loading the specimen till the yield point reached. This is indicated by the elongation scale showing high valves of extension for the same amount of increase in load.
11. After yield point is reached, continue to apply the load till fracture of the specimen occurs.
12. Immediately after the specimen breaks, press the pump "off" switch on the control panel, close the right control valve and then open the left control valve slowly to release the load
13. Broken specimen is removed from the machine.

14. By joining the two broken halves of the specimen final length between the gauge points and gauge diameter at neck of the specimen is measured by using a steel rule and vernier calipers respectively.
15. Yield point, ultimate tensile strength, percentage elongation, percentage reduction in area and modulus of elasticity are calculated.
16. Stress strain diagram is plotted and all the points are indicated.

Fig (4.1): UTM testing machine

4.3. Standard test specimen

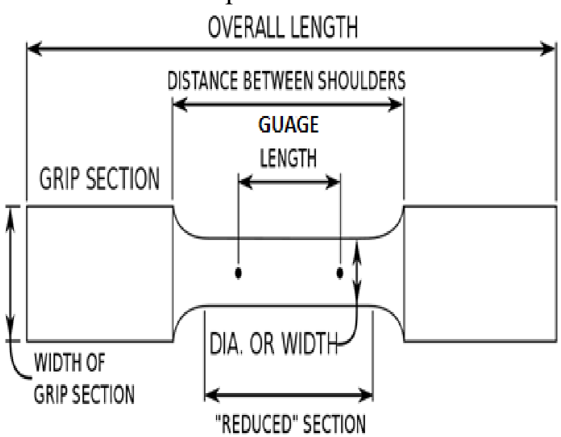


Fig 4.2 (a): Standard Test Specimen

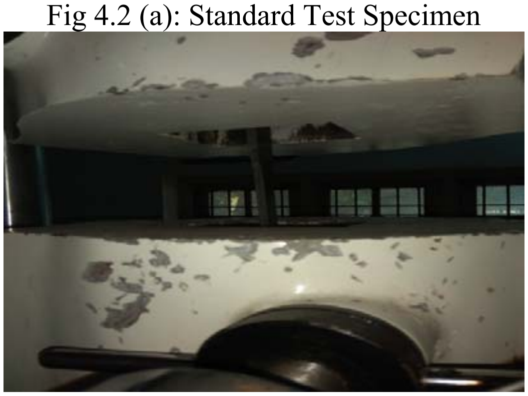


Fig 4.2 (b): Tensile test specimen in UTM machine

Fig 4.2 (c): Specimen after Tensile test

4.4 Impact test

4.4.1 Theory:

The loads that are suddenly applied are known as impact loads. The high resistance of material to fracture under suddenly applied loads is known as "impact strength". The important mechanical properties of engineering materials like strength, toughness etc., varies with the type of loading. Materials exhibit poor performance under dynamic or shock loads. Hence it is importance to know how strength and toughness varies with impact or shock loads.

The impact strength is calculated according to the following relation; I=K/A

Where I= Impact strength in J/m^2

K=Impact energy absorbed in J and

A= cross sectional area of the specimen below the notch before the test in m^2

The impact strength depends largely on the shape of the specimen and the notch. The values determined with other specimens, therefore may not be compared with the each other.

4.5 Charpy Test

4.5.1 Experimental Setup:

- Production drop angle 140°
- Pendulum effective weight 209N
- Striking velocity of pendulum 5.346 m/s
- Pendulum impact energy 300 J
- Minimum Scale graduation 2J

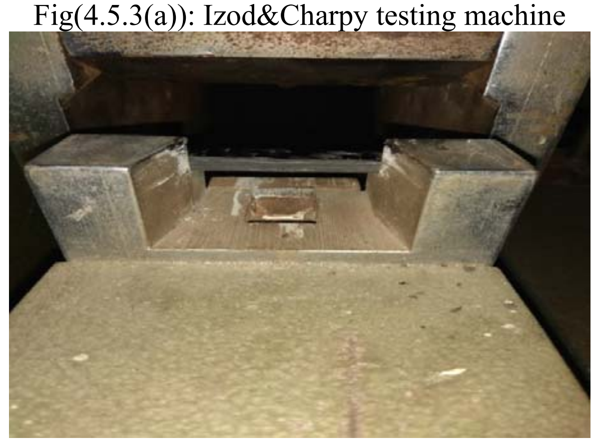
4.5.2 Description of the Equipment:

The pendulum impact-testing machine consists of a robust frame, pendulum support for the specimen and a measuring dial. The pendulum is clamped to the pendulum shaft. The pendulum consists of the pendulum pipe and the pendulum hammer having U-shaped design into this, a striker is mounted for conducting impact test. The range, within which the pendulum is swinging, is partially protected by the guard. A latch is provided which keeps the pendulum in elevated position. A lever is operated for operating the latch and releasing the pendulum. There is a dial attached concentrically with the pendulum shaft. The scale is designed such that the impact energy absorbed in breaking the specimen can be read directly in Joules. A separate striker is provided for conducting charpy test.

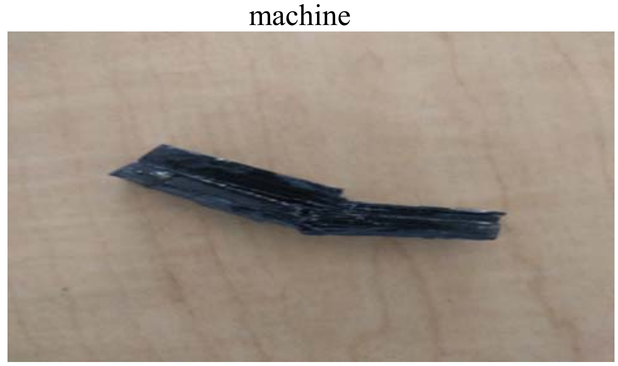
4.5.3 Procedure:

1. With the help of a clamping device firmly secured the charpy striker to the bottom of the hammer of the swinging pendulum.
2. Before conducting the actual test, determined the frictional loss in the impact testing machine by conducting the free fall test without specimen fixed.
3. For determining the frictional losses in the machine, first adjusted the reading pointer along with the pointer carrier to 300J on the dial and then raise the hammer by hands and latch it with the angle of fall being 140°.
4. Then release the hammer by operating the latch lever. If the pointer coincides with the zero on the scale it indicates that there is no friction loss. But if the pointer shows a reading on the scale it indicates the energy loss due to friction from this reading, it is to be confirmed whether the friction loss is more than 0.5% of the initial potential energy. If it exceeds then the friction loss is added to the final reading.
5. After the friction loss is determined, adjusted the pointer along with pointer carrier to 300J on the dial, when the pendulum is hanging freely vertical.
6. Then again raised the hammer and latch it with the angle of drop being 140°.
7. After the latched the hammer carefully, fixed the charpy test specimen as a cantilever beam firmly in specimen support with the help of clamping screw. Fixed the specimen such that the notch faces the striking edge of the pendulum striker.
8. After fixing the specimen carefully observe that there is no person in the range of swinging pendulum by operating the latch lever, so that it fractures the specimen and then rises to a certain height.
9. By operating the pendulum brake, carefully stop the oscillations of pendulum when it returned after one swing.
10. Now, the reading shown by the pointer on the scale, which indicates the impact Strength or toughness of the material being tested in joules is noted.
11. Finally, removed the broken pieces of the specimen by loosening the clamping Screws and the failure takes place in the specimen are carefully observed.

Fig(4.5.3(a)): Izod&Charpy testing machine



Fig(4.5.3(b)): specimen in charpy testing machine



Fig(4.5.3 (c)): Specimen after Charpy test

4.6 Bending Test:

Bending test is a procedure to determine the relative ductility of metal that is to be formed (usually sheet, strip, plate or wire) or to determine soundness and toughness of metal (after welding, etc). The specimen is usually bent over a specified diameter mandrel. The four general types of bends are:

- Free bend
- Guided bend(ASTM E190)
- Semi-guided bend(ASTM E290)
- Wrap around bend.

Principle

The bend test is a ductility test, which is employed to evaluate the ability of metallic materials to undergo plastic deformation in bending. The test consists of submitting a test piece of round, square, rectangular or polygonal cross-section to plastic deformation by bending without changing the direction of loading until specified angle of bend is reached.

Fig(4.6.1): Bending test

V CALCULATION

5.1 Tensile test

In Tensile test,

Specimen data is

Length L=250mm

Breadth B=18mm

Thickness D=6mm

Max. Load W=42039.932N

Tensile Strength=W/(B*D)

$=389.26N/mm^2$

5.2 Charpy and Impact test

Initial energy in scale =300J

After testing residual energy in scale =28J

Absorbed energy =300-28

=272J

5.3 Bending test

Steel leaf spring weight W=10.776kg

Without load clearance between ground and ends of leaf spring δ=169mm

At 40kg

The deflection δ=169-155

δ=14mm

At 60kg

The deflection δ=169-149

δ=20mm

At 70kg

The deflection δ=169-146

δ=23mm

Composite leaf spring weight W=1.722kg

Without load clearance between ground and ends of leaf spring δ=188mm

At 40kg

The deflection δ=188-102

δ=86mm

At 60kg

The deflection δ=188-82

δ=106mm

At 70kg

The deflection δ=188-77

δ=111mm

VI CONCLUSION

The Composite leaf spring is manufactured by combination of resin and carbon fiber. It is tested to Tensile, Charpy and Impact, Bending Test. In Tensile test the Composite leaf spring is capable of handle Ultimate load of42.039KNand the corresponding Ultimate tensile strength of $35.038KN/cm^2$. This Tensile Test has been done according to ASTM D638 Standards. The Charpy and Impact Test on Composite leaf springhas also been done according to ASTM D790-03 Standard and its capable of Load at the specimen Fracture is 9600N and at this point the cross breaking strength 28N-m. In bending test the Composite leaf spring is deflected under the loads(40kg,60kg,70kg) and the composite leaf spring is deflected up to(86mm,106mm,111mm) when the load is acted on the ends of the composite leaf spring.

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