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Comparison between GFRP and CFRP Composite Power Take-off Shaft in Helicopters for Prescribed Torque and Geometrical Constraints

Rakesh Potluri[1] and Krishna Kanth Ketha[2]

[1,2]M.Tech Student in PVPSIT, Kanuru, Vijayawada – 07
E-mail: [1]y09me042@gmail.com, [2]krishna.krishna133@gmail.com

Abstract—*In the modern world, there is a huge demand for very speed and efficient mechanical systems in every field. In the design the companies are exploring the use of composite materials as a replacement for the conventional materials especially in the industries like aerospace, automobiles…etc. In particular polymer matrix composites are playing more widely used in the design of the aerospace components because of their high stiffness and strength to weight ratio's.*

The rotor shafts play a very major role in power transmission systems which are very crucial parts of any mechanical system like helicopter rotor's, PTO shaft in trucks, tractors, heavy equipment…etc. In this paper we try to design a hallow PTO shaft with a GFRP and CFRP composite materials for a prescribed torque transmission requirements and geometric constraints and compare the efficiency of each other which is very important consideration in the design of a shafts.

1. INTRODUCTION

Composite materials are different materials which have interesting properties such as high strength to weight ratio's when compared to metals, which make them very attractive for rotating systems. Attempts are being made to replace metal shafts by composite ones in many applications: drive shafts for helicopters, centrifugal separators, and cylindrical tubes for the automotive and marine industries. They also provide designers with the possibility of obtaining predetermined behaviors, in terms of position of critical speeds, by changing the arrangement of the different composite layers: orientation and number of plies.

On the other hand, these materials have relatively high-damping characteristics. For a rotor made with composite materials, internal damping is much more significant companied with those associated with a metal rotor.

1.1 Composite Material

A material composed of 2 or more constituents is called composite material. Composites consist of two or more materials or material phases that are combined to produce a material that has superior properties to those of its individual constituents. The constituents are combined at a macroscopic level and or not soluble in each other. The main difference between composite and an alloy are constituent materials which are insoluble in each other and the individual constituents retain those properties in the case of composites, whereas in alloys, constituent materials are soluble in each other and forms a new material which has different properties from their constituents. Classification of Composites Polymer matrix composites Metal matrix composites Ceramic Matrix.

B) Advantages of Composites

The advantages of composites over the conventional materials are: High strength to weight ratio, high stiffness to weight ratio, high impact resistance, better fatigue resistance, Improved corrosion resistance, Good thermal conductivity, Low Coefficient of thermal expansion. As a result, composite structures may exhibit a better dimensional stability over a wide temperature range, high damping capacity.

C) Limitations of Composites

The limitations of composites are: Mechanical characterization of a composite structure is more complex than that of a metallic structure, the design of fiber reinforced structure is difficult compared to a metallic structure, mainly due to the difference in properties in directions, the fabrication cost of composites is high, rework and repairing are difficult, they do not have a high combination of strength and fracture toughness as compared to metals and they do not necessarily give higher performance in all properties used for material selection.

D) Applications of Composites

The common applications of composites are extending day by day. Now a day they are used in medical applications too. The other fields of applications are:

Automotive: Drive shafts, clutch plates, engine blocks, push rods, frames, valve guides, automotive racing brakes, filament–wound fuel tanks, fiber Glass/Epoxy leaf springs for heavy trucks and trailers, rocker arm covers, suspension arms and bearings for steering system, bumpers, body panels and doors.

Space: payload bay doors, remote manipulator arm, high gain antenna, antenna ribs and struts etc.

Marine: Propeller vanes, fans & blowers, gear cases, valves & strainers, condenser shells.

Chemical Industries: Composite vessels for liquid natural gas for alternative fuel vehicle, racked bottles for fire service, mountain climbing, underground storage tanks, ducts and stacks etc.

Aircraft: Drive shafts, rudders, elevators, bearings, landing gear doors, panels and floorings of airplanes etc.

Electrical & Electronics: Structures for overhead transmission lines for railways, Power line insulators, Lighting poles, Fiber optics tensile members etc.

Sports Goods: Tennis rackets, Golf club shafts, Fishing rods, Bicycle framework, etc.

E) Carbon Fiber

Carbon fiber is a material consisting of fibers about 5–10 μm in diameter and composed mostly of carbon atoms.

To produce carbon fiber, the carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fiber as the crystal alignment gives the fiber high strength-to-volume ratio. Several thousand carbon fibers are bundled together to form a tow, which may be used by itself or woven into a fabric.

The properties of carbon fibers, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion, make them very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive when compared to similar fibers, such as glass fibers or plastic fibers.

Carbon fibers are usually combined with other materials to form a composite. When combined with a plastic resin and wound or molded it forms carbon fiber reinforced polymer which has a very high strength-to-weight ratio, and is extremely rigid although somewhat brittle. However, carbon fibers are also composited with other materials, such as with graphite to form carbon-carbon composites, which have a very high heat tolerance.

F) Glass Fiber

Fiberglass is a type of fiber reinforced plastic where the reinforcement fiber is specifically glass fiber. The glass fiber may be randomly arranged but is commonly woven into a mat. The plastic matrix may be a thermosetting plastic- most often epoxy, polyester resin- or vinyl ester, or a thermoplastic.

The glass fibers are made of various types of glass depending upon the fiberglass use. These glasses all contain silica or silicate, with varying amounts of oxides of calcium, magnesium, and sometimes boron. To be used in fiberglass, glass fibers are made with very low levels of defects.

Fiberglass is a strong lightweight material and is used for many products. Although it is not as strong and stiff as composites based on carbon fiber, it is less brittle, and its raw materials are much cheaper. Its bulk strength and weight are also better than many metals, and it can be more readily molded into complex shapes.

Applications of fiberglass include aircraft, boats, automobiles, bath tubs and enclosures, swimming pools, hot tubs, septic tanks, water tanks, roofing, pipes, cladding, casts, surfboards, and external door skins.

1.2 Power Take-off Shafts

A power take-off or power takeoff (PTO) is any of several methods for taking power from a power source, such as a running engine, and transmitting it to an application such as an attached implement or a separate machine.

Most commonly, it is a system comprising a splined output shaft on a vehicle like tractor's or trucks and machinery designed so that a PTO shaft, a kind of drive shaft, can be easily connected and disconnected, and a corresponding input shaft on the application end. The power take-off allows implements or another external machine to draw energy from the engine.

Semi-permanently mounted power take-offs can also be found on industrial and marine engines. These applications typically use a drive shaft and bolted joint to transmit power to a secondary implement or accessory. In the case of a marine application, such shafts may be used to power fire pumps.

In aircraft applications, such an **accessory drive** may be used in conjunction with a constant speed drive. Jet aircraft have four types of PTO units, internal gearbox, external gearbox, radial driveshaft, and bleed air which are used to power engine accessories. In some cases, aircraft power take-off systems also provide for putting power into the engine during engine start

2. METHODOLOGY

In this paper the power take-off shaft that is used in a helicopter was designed with the dimensions that were taken from the Study that was conducted by NAL. At first we recreated the same model in order to verify the results accuracy of our FEA model and the after we had an satisfactory convergence with those of the experimental results provided in the study, then we applied the same FEA model to perform our own simulation or virtual experimentation. The boundary conditions and the torque values were taken from the same study and this was applied to the PTO shafts that were made out of both unidirectional and woven CFRP and two unidirectional GFRP materials and comparison was made between them. A comparison of layer-wise stress was also made. The design of the shaft was done in ANSYS Workbench. The total experimentation was done in a virtual environment called ANSYS Workbench which applies the technique of 'FEM' to solve the prescribed problem and the results of these simulations were taken to compare all the cases of the virtual experimentation.

3. SIMULATION

First as stated we have taken the feasibility report that has been produced by the NAL people and with those dimensions designed a helicopter power take-off shaft in the form of a surface in order to apply the layered element formulation. Then with the help ANSYS Workbench tools we modeled the layup as shown below with four different materials which are available in the form of a Prepreg's starting with:

1. Epoxy embedded with woven carbon fabric.
2. Epoxy embedded with carbon fiber in unidirectional arrangement.
3. Epoxy embedded with e-glass fiber in unidirectional arrangement.
4. Epoxy embedded with S-glass fiber in unidirectional arrangement.

For the arrangement we calculated the total von-mises

Stress, total deformation, Torsional Stiffness.

The length of the rotor is taken as 376 mm and 18 composite layers were modeled on them.

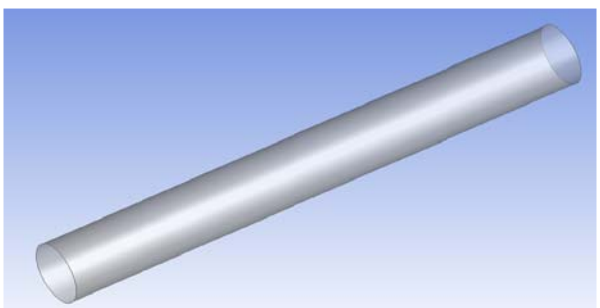


Fig. 1: Surface model Of the Shaft

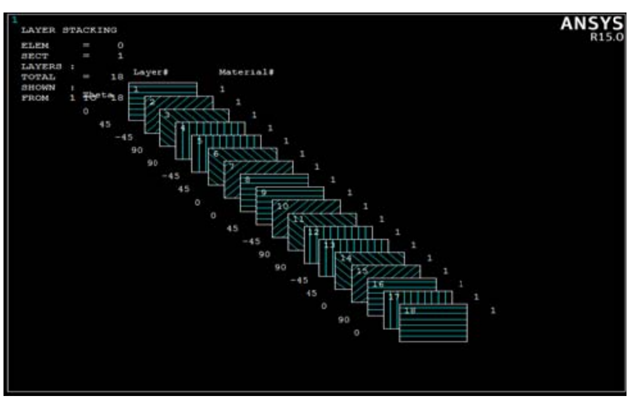


Fig. 2: Composite Layup Plot for Shaft

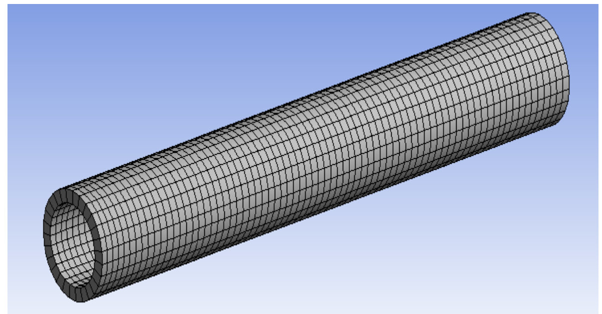


Fig. 3: Meshed Model of Composite Rotor

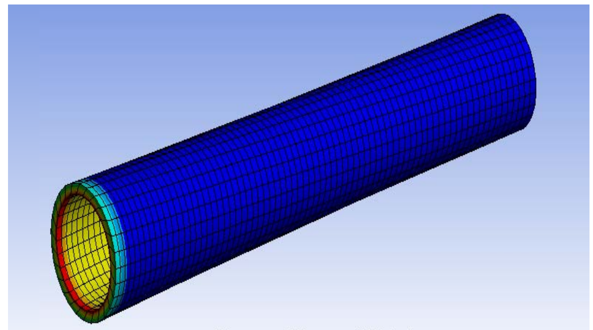


Fig. 4: Von-Misses stress in Composite Rotor

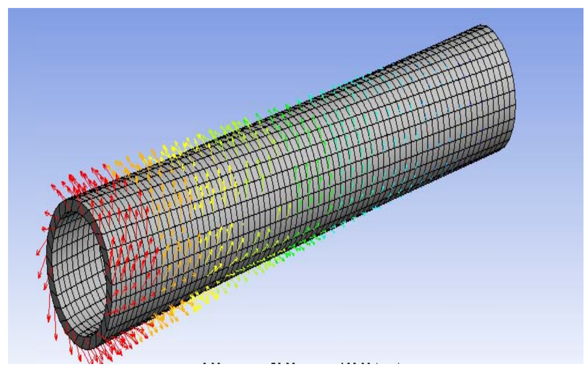


Fig. 5: Total Deformation in Composite Rotor

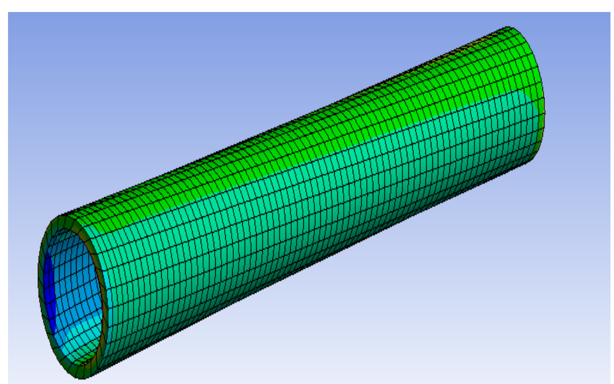


Fig. 6: Shear Stress in Composite Rotor

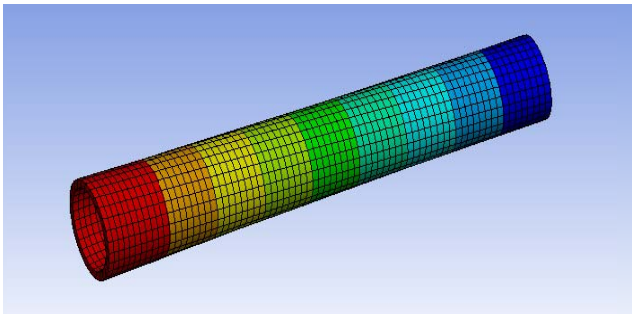
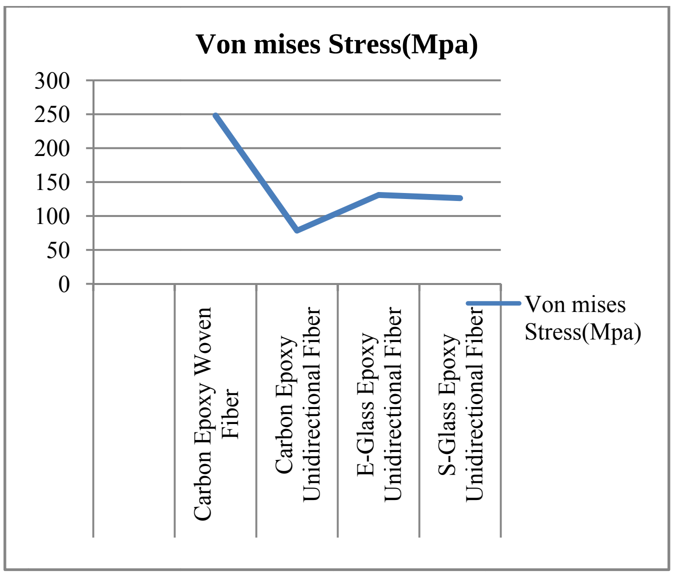
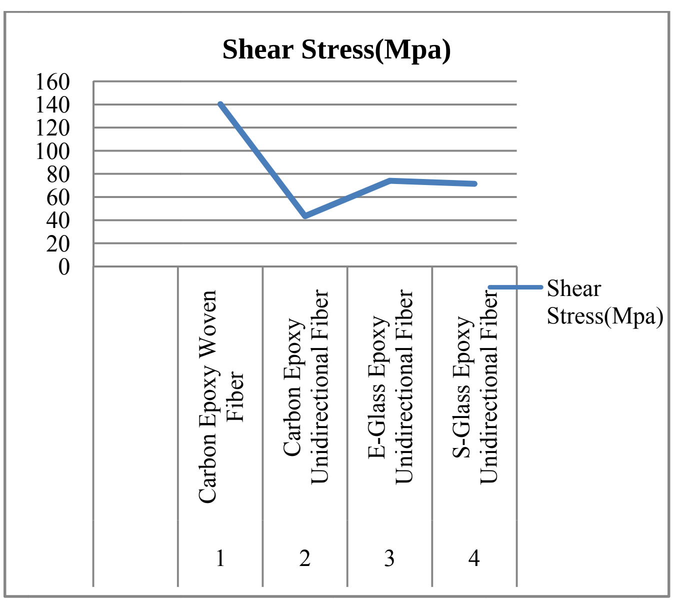


Fig. 7: Rotation about Z in Composite Rotor

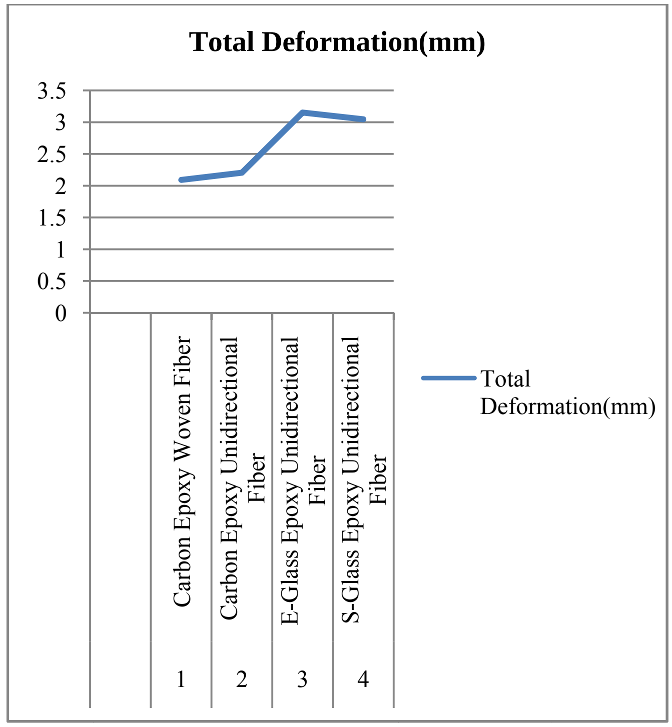
The values that are obtained for Different composite Materials were shown below in the form of the Graphs:



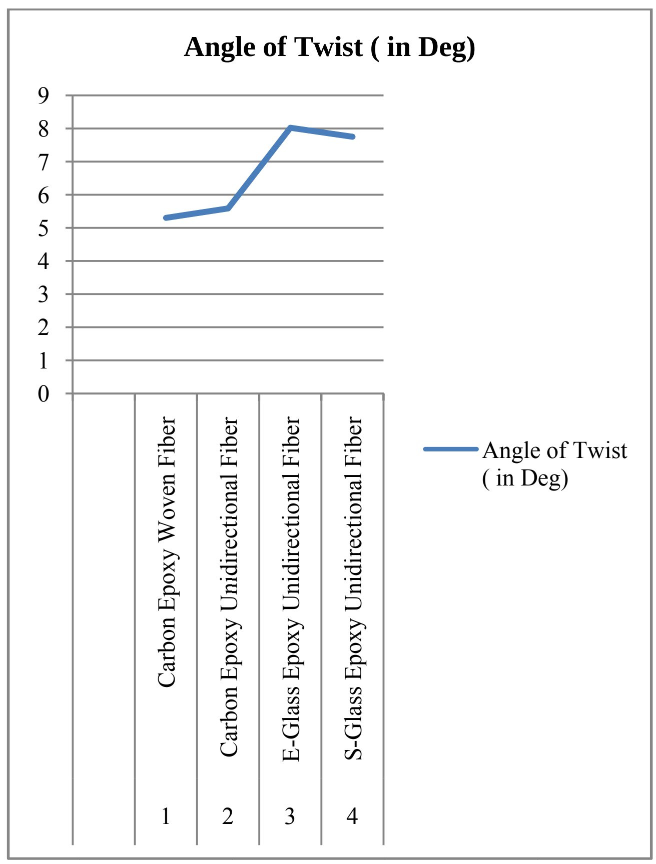
Graph 1: Von mises Stress



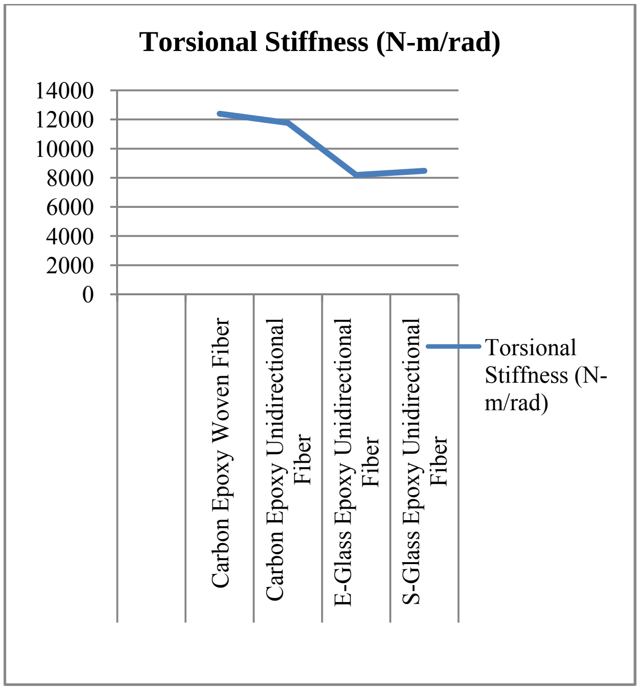
Graph 2: Shear Stress



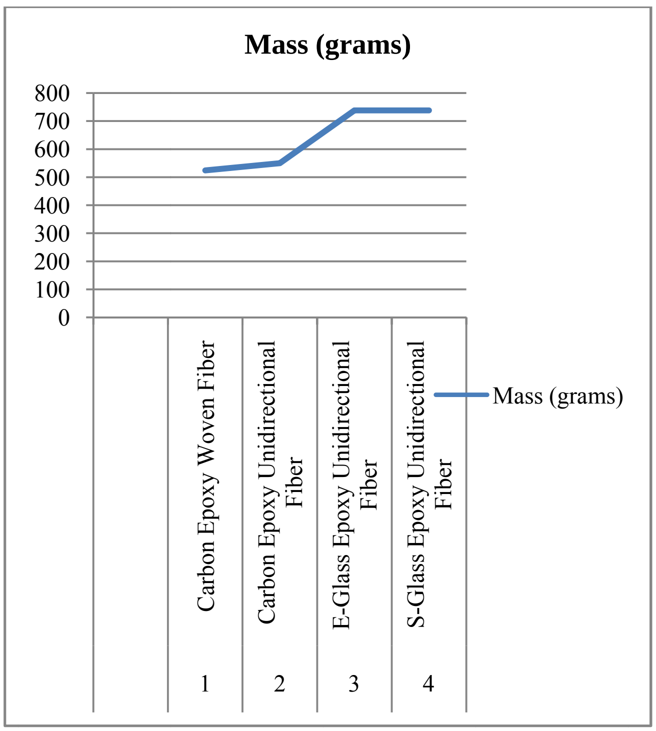
Graph 3: Total Deformation



Graph 4: Angle Of twist



Graph 5: Torsional Stiffness



Graph 6: Total Mass

After all the we also tested the composite shafts for failure using Tsai – Wu failure Criteria and caluclated the inverse reserve factor and plotted the Failure for the layers and for all the materials which becomes the main for choosing the material for the prescribed conditions the shaft has to be subjected to.

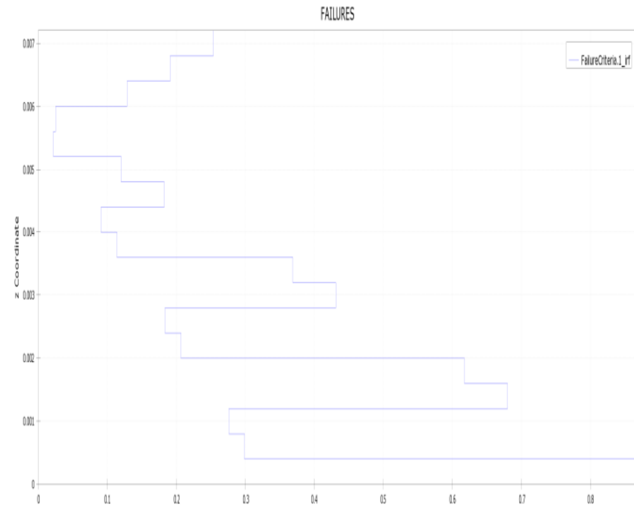


Fig. 8: Layer-wise Failure Plot of the Composite Shaft

For

Material 1

Fig. 9: Layer – Wise Failure plot of the Composite Shaft

For

Material 2

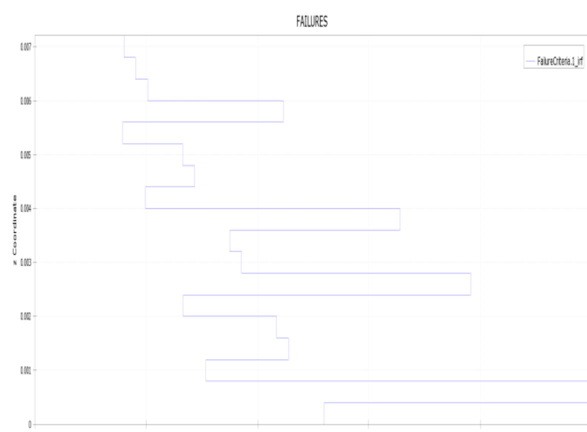


Fig. 10: Layer – Wise Failure plot of the Composite Shaft

For

Material 3

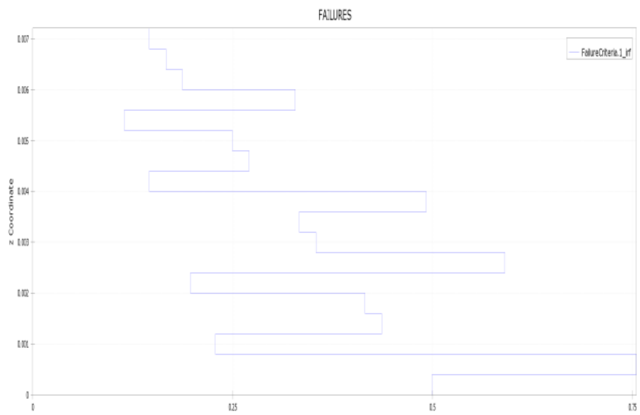


Fig. 11: Layer-Wise Failure Plot of the Composite Shaft

For

Material 4

4. CONCLUSION

1. First the FEA model of the composite rotor was created, tested and validated with the experimental results from the report.
2. Then with the same FEA model was used to modelling of all the cases in this work and the best alternative was found from the ansys experimentation.
3. From the above graphs if our requirement is less weight and high strength without the concern about cost then our best alternative is Uni- Directional Carbon fiber placed in the Epoxy resin.
4. But if cost is the main priority then the best alternative is unidirectional E-glass fiber embedded in Epoxy resin is the best one but there is an increase of about 30 – 34 % increase in the weight of the component when compared with carbon fiber composite.
5. If we observe the ply-wise failure plots for all the materials we can say that unidirectional S-glass fiber in epoxy resin has the best behavior.

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