Design and Development of Composite/ Hybrid Propeller Shaft

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Abstract: *The present paper is aimed to design and develop a propeller shaft made of fiber reinforced plastic material (FRP). The work is divided in to four parts, first of them is characterization of the material in which the material properties for the particular fabrication tectonic is determined, second is to determine the better orientation among [0,90]$_s$, [±45]$_s$ and [60]$_s$ of the fiber by simulation results performed in ANSYS. Third is to fabricate two propeller shafts, one made of only Glass/Epoxy and the other an Hybrid shaft (Glass/Epoxy and Aluminum) and the fourth is to perform the static test on the fabricated shafts.*

Keywords: Design and development of composite/hybrid propeller shaft using fiber reinforced plastic material (FRP).

1. Introduction

In the present work aims to design and fabricate a propeller shaft made of composite material which could replace the conventionally available shaft. The whole work can be divided in to the following steps:

- Estimation of material properties.
- Geometrical modeling.
- FEA analysis.
- Fabrication and experimentation.

The material properties are estimated for the glass/epoxy composite based on classical laminate theory. The geometric model is prepared in ANSYS plat form. For this the required coordinates of the shaft. Then the model is fabricated. The present work is aims to design and fabricate a composite drive shaft which can replace the existing steel drive shaft.

2. Estimation of Material Property

As a glass fiber tape instead of the conventional material (glass fiber rolls) is being used, it is required to estimate the material property of the tape before designing. For this a standard test specimen has to be prepared with different orientation and tested. The standard specimen size should be 25mmX150mm.The test specimen is being fabricated using hand lay up method as it was the simplest one to do. This method is commonly used production processes. Generally wooden are FRP moulds are used to produce components. This method is flexible and size of the component has no constraint but repeatability of quality depends on the skill of the worker. FRP Component can be produced in the following steps.

1) Mold is treated with mold release agent;
2) Thin gel coat (resin, colored) is applied, to be the outside surface of molding;
3) When gel coat has partially set layers of resin and fiber is applied, the fiber is in the form of mat or cloth; each layer is rolled to impregnate the fiber with resin and remove air;

4) Part is cured.
5) Fully hardened part is removed from mold.

3. Preparation of Test Specimen

Figure 2.1: Test specimen preparations

Figure 2.1: (a) Test specimen of orientation [±45°]

Figure 2.1: (b) Test specimen of orientation [0, 90°]

Estimation of material properties can be done in two stages:

- Estimation of Young's Modulus
- Estimation of Volume Fraction

3.1 Estimation of Young's Modulus

The standard specimen prepared is tested on universal testing machine for young's modulus in X-direction.

Figure 2.1.1: (a) specimen testing for young's modulus in X-direction

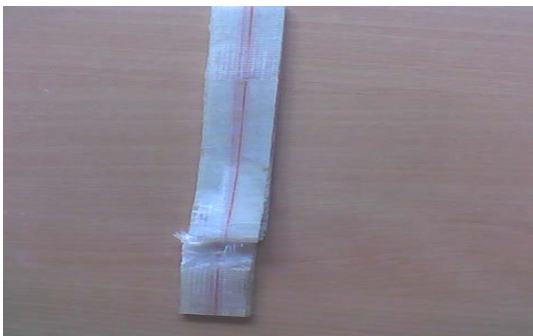**Figure 2.1.1:** (b) failure of specimen after test at 45°

Figure 2.1.1: (c) failure of specimen after test at 90°

Graphs

After the Tensile Test, a graph is drawn
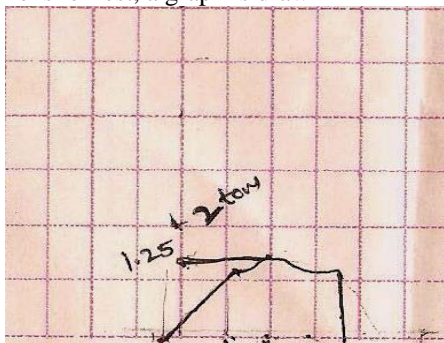
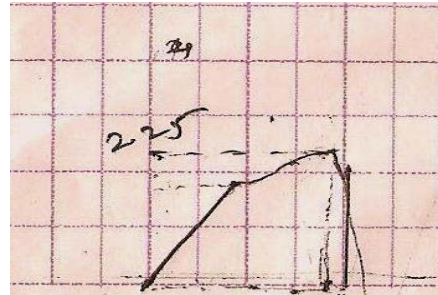
Figure 3.2: (a) Stress v/s load at [±45°]

Figure 3.2: (b) Stress v/s load at [0, 90°]

Theoretical Calculation:

Stress Vs load at (45^0)

As we know that
$\sigma = E\epsilon$
$E = \sigma/\epsilon$
Where,
$E = Wl/A\delta l$
$E_{xx} = Wl/A\delta l$
Here,
E_{xx} is young's modulus in x-direction
W is load applied
A is cross sectional area
L is length of specimen
δl is change in length
At (±45°)
$E_{xx} = (1.25*1000/25*6)*150/8$
$E_{xx} = (1.25*1000*150) / (25*6*8)$
$E_{xx} = 1532.8125$ Kgf/mm^2
$E_{xx} = 15.32$ Gpa.

Stress Vs load at (90^0):

Change in Length (δl) = 19mm
Length = 150-19 = 131mm
$E_{xx} = (2.25*1000) / (45*25)* 131$
$E_{xx} = 137.89474$ Kgf/mm^2
$E_{xx} = 13527.474$
$E_{xx} = 13.5$ Gpa

3.2 Designing of Shaft

A CAD model is developed in ANSYS using the arc tangent method and the model is shown in figure 3.1
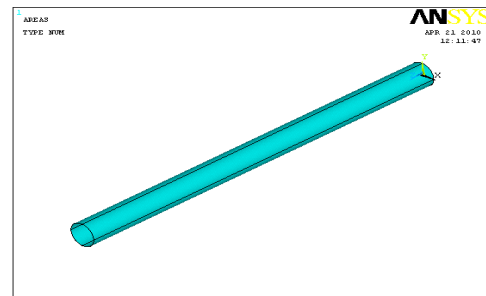

Figure 3.1: Designed model of shaft

3.2.1 Meshing of Shaft Model

The model is then meshed using SHELL63 element and the description of it is discoursed in section 3.1. The meshed model is shown in fig: 3.2.
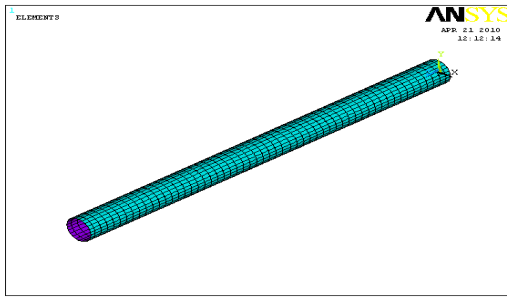
Figure 3.2: meshed model of shaft

3.2.1.1 Boundary Conditions

The meshed model is then analyzed (static) and the boundary conditions are:

- One end is fixed (All DOF).
- A moment of 124 N-m is applied at the other end.

The following are the results for steel shaft and composite shaft with different angle of ply and different thickness of the composite shaft.
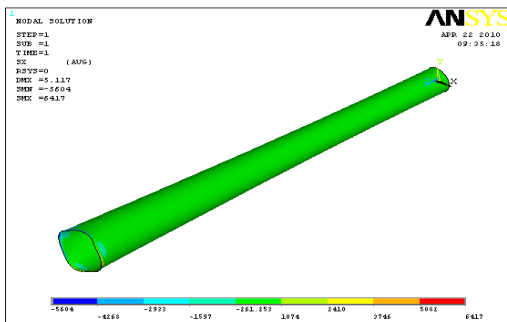
Results for Steel Shaft:

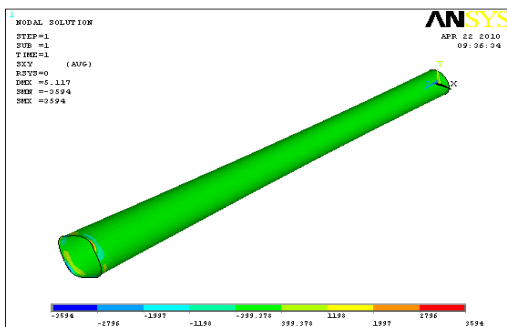**Figure 3.8:** (a): Deformation of steel shaft

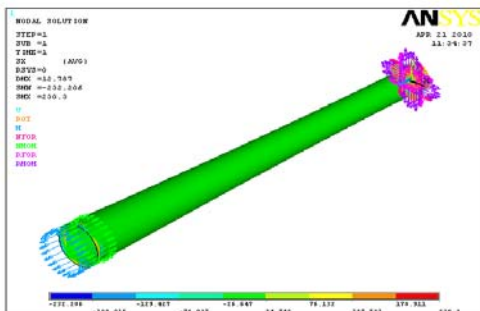**Figure 3.8:** (b) Shear-Stress in XY-direction

RESULTS FOR 0^0 ORIENTATION:

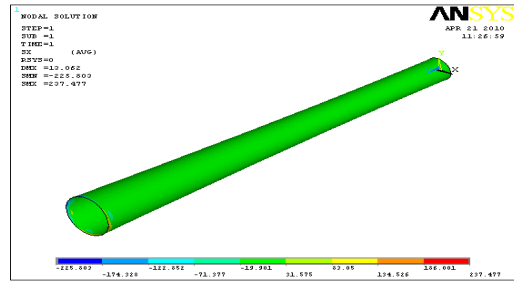**Figure 3.9:** (a): Deformation at 0^0 orientations at 8mm thickness

Figure 3.9: (b): Deformation at 0^0 orientations at 10mm thickness
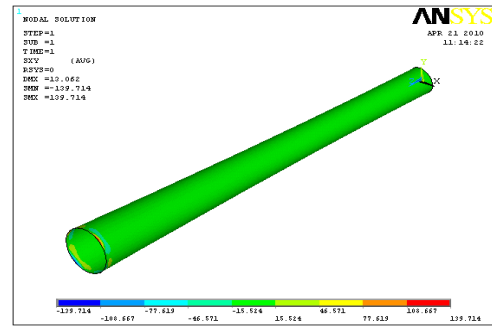

Figure 3.9: (c): shear-stress in xy-direction at 0^0 orientations at 10mm thickness

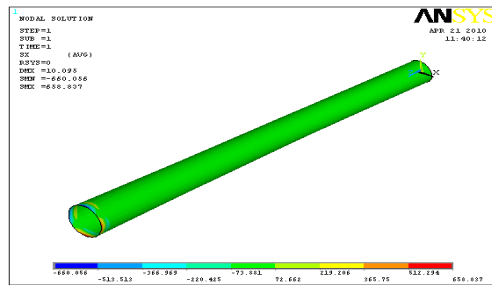RESULTS FOR 45^0 ORIENTATION:

Figure 3.10: (a): Deformation at 45^0 orientations at 4mm thickness
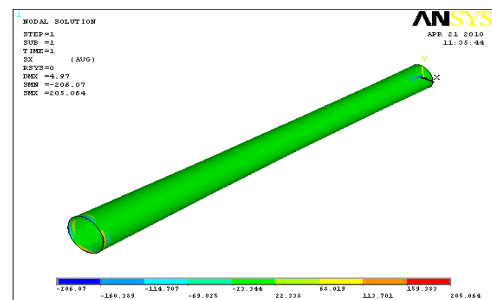

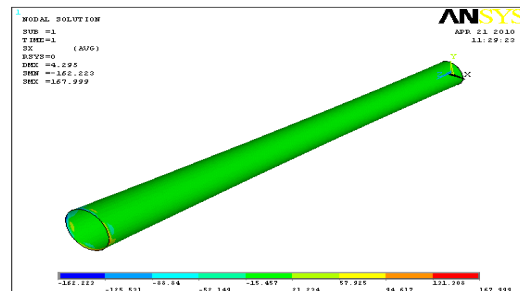**Figure 3.10:** (b): Deformation at 45^0 orientations at 8mm thickness

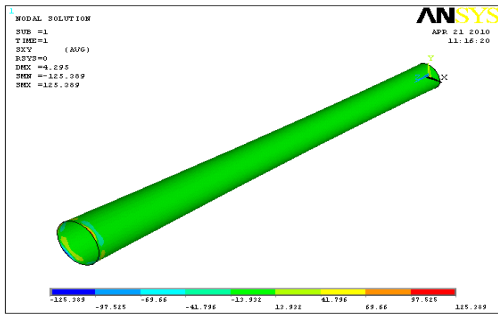**Figure 3.10:** (c): Deformation at 45^0 orientation at 10mm thickness

Figure 3.10: (d): shear-stress in xy-dir at 45^0 orientations at 10mm thickness.
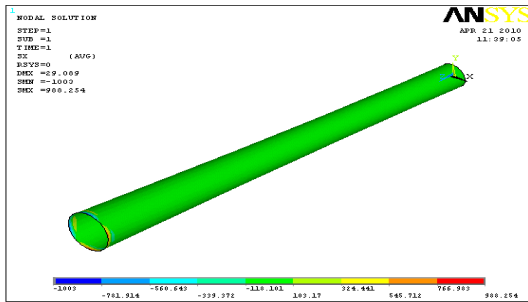
RESULTS FOR 90^0 ORIENTATION:

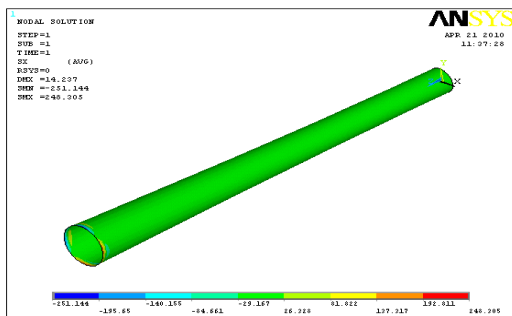**Figure 3.11:** (a) Deformation at 90^0 orientations at 4mm thickness

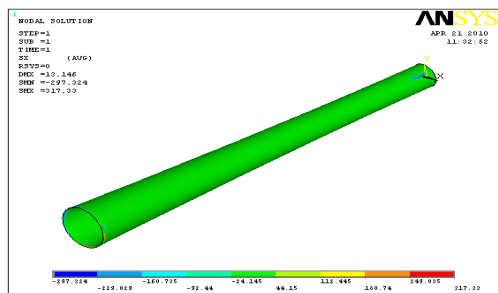**Figure 3.11:** (b): Deformation at 90^0 orientations at 8mm thickness

Figure.3.11: (c): Deformation at 90^0 orientations at 10mm thickness
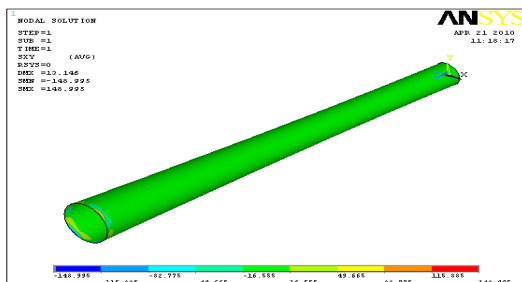

Figure.3.11: (d): Shear-Stress in XY-dir at 90^0 Orientation at 10mm thickness.

4. Fabrication

In general cylindrical components made from composite material are prepared using filament winding machine. Filament Winding is the process of winding resin-impregnated fiber or tape on a mandrel surface in a precise geometric pattern. This is accomplished by rotating the mandrel while a delivery head precisely positions fibers on the mandrel surface. By winding continuous strands of carbon fiber, fiberglass or other material in very precise patterns, structures can be built with properties stronger than steel at much lighter weights. Filament winding can produce extremely high stiffness-to-weight and strength-to-weight structures compared to traditional all metal designed structures such as pressure vessels. Applications that capitalize on this are rocket propellant tanks and solid rocket motor casings for the aerospace industry and high pressure fuel storage tanks for hydrogen powered automobiles for the automotive industry. There is a difficulty in accurately predicting the behavior of these structures that derives from the varying orientation of the wound filaments throughout the structure. The standard capabilities of commercial finite element codes are inadequate to model the variation of fiber orientation in a practical way. This machine is expensive and required sophisticated control system instead of this, the winding processes is done manually.

4.1 Fabrication of simple composite shaft:

The glass tape is hand wounded on the poly vinyl chloride (PVC) mandrel placed on a wood turning lathe which could be operated manually. The angle of lay up 45° marked on mandrel and the process is started by manually rotating the head stock of the wood turning lathe. A single layer is wound on simultaneously resin is applied by hand. The next layer is wound on the first one and this process is repeated until the required thickness is obtained. The mandrel is then removed from the composite shaft. The mandrel is initially applied with poly vinyl alcohol (PVA) which is a releasing agent

Figure 4.1: Winding of Fiber Tape on PVC Pipe

Figure 4.2: Applying of Resin and Winding Tape Simultaneously

4.2 Fabrication of hybrid shaft

The glass tape is hand wounded on the aluminum mandrel placed on a wood turning lathe which could be operated manually. The angle of lay up 45° marked on mandrel and the process is started by manually rotating the head stock of the wood turning lathe. A single layer is wound on simultaneously resin is applied by hand. The next layer is wound on the first one and this process is repeated until the required thickness is obtained. Here the mandrel is not removed as hybrid shaft contains the aluminum inside it

Figure 4.3: Winding of Tape on Aluminum Mandrel

Figure 4.4: First Layer of Tape Winded on Mandrel

Figure 4.5: Applying Resin

Figure 4.6: Finishing Touch

5. Results

The tensile test performed on the laminates performed on different orientation made from the glass fiber tape yield the results:

E_{xx} = 13.5 GPa. For [0, 90] orientation.
E_{xx} = 15.3 GPa. For [±45] orientation.
The volume fraction evaluated from the burn test are:
V_f = 65 % for [0, 90].
V_f = 55 % for [±45].

From the computer simulation, the deformation of steel shaft is 5.117mm. The graph below shows the variation of deformation with respect to the thickness of composite shaft made from different orientation.
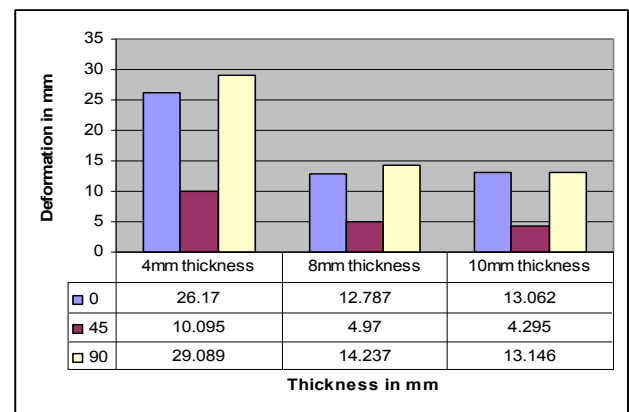

	4mm thickness	8mm thickness	10mm thickness
0	26.17	12.787	13.062
45	10.095	4.97	4.295
90	29.089	14.237	13.146

Figure 5.1: Thickness v/s Deformation

A simple composite shaft and a hybrid shaft are fabricated using a simple technique of hand winding method.

6. Conclusion

- Orientation of ±45° is found to be better for the composite drive shaft compare to convectional steel drive shaft.
- A simple hand winding method has been developed for fabrication of composite shaft.
- Simple composite shaft and hybrid aluminum-glass/epoxy shaft is fabricated by simple winding method.

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Mujahid Khan received the B. Tech degree in Mechanical Engineering and M. Tech. Degree in CAD/CAM from Nizam Institute of Engineering and Technology in 2010 and 2012, respectively. Won a Silver medal National Design and Research Forum, the Institution of Engineers (India) has awarded in Metallurgical and Materials Engineering discipline. He is now with Nizam Institute of Engineering and Technology.