CHAPTER 6

FABRICATION OF ANGLE-PLY SHAFTS USING FILAMENT WINDING TECHNIQUE

6.1 INTRODUCTION

This chapter describes the manufacturing process of angle-ply shafts of E-Glass/Epoxy and E-Glass/Vinylester composites using wet filament winding process and fabrication of end joints are explained below.

6.2 WINDING SIMULATION FLOW CHART

The winding simulation program is written in the AUTOLISP parametric programming language and is operated within the AUTOCAD (release 14) environment. The overall program structure shown in Figure 6.1 (Lye and Boey 1995), consists of two sub-models; mandrel modeling and winding pattern generation. The simulation process begins with specifying the mandrel or component profile and the size to be wound, such as the segment diameters, lengths and geometrical tapered angles. The next step is to simulate the appropriate winding pattern on the newly created 3-D model. Currently, the program can generate hoop and helical winding only, as these are used more commonly in the shaft fabrication. In the simulating of the winding pattern, the four main parameters considered are the spiral winding generation, the pattern bandwidth, the dwell and the winding pattern closure. The filament winding process of the composite shaft is controlled by the mandrel rotational speed, the linear carriage speed and the fiber tension. As the continuous fiber is being fed
and wrapped around the created model, a spiral pattern is generated owing to the mandrel and carriage movements, with tension assumed to be constant.

Figure 6.1 Overall flow chart of the winding simulation program
Figure 6.2 Illustration of a one circuit- lay

Figure 6.3 Effect of overlaying between circuits
6.3 ANGLE-PLY SHAFT TUBE FABRICATION

Using the aforementioned 2-axis filament-winding machine, composite drive shaft tubes of E-Glass/Epoxy and E-Glass/Vinylester composites of varying stacking sequence to satisfy the design constraints were fabricated. Vetrotex E-Glass fiber with 2400 Tex and 14 μm diameter was used as reinforcement with the matrix Ciba Geigy/LY 556 epoxy resin with a glass transition temperature, $T_g$, of 140 °C. The hardener and accelerator added to epoxy matrix was Ciba Geigy/HY 917 and Ciba Geigy/DY 070 for curing purpose. Another combination is with E-glass fiber and GR 200-60 Vinylester resin. Mechanical properties of these reinforcements and matrix materials are given in Table 6.1 and 6.2 respectively.

Table 6.1 Mechanical properties of the fiber*

<table>
<thead>
<tr>
<th>Fiber</th>
<th>$E_1$ (GPa)</th>
<th>$E_2$ (GPa)</th>
<th>$G_{12}$ (GPa)</th>
<th>$\nu_{12}$</th>
<th>$\sigma_{TS}$ (GPa)</th>
<th>$\rho$ (g/cm$^3$)</th>
<th>$\sigma_{ult}$ (GPa)</th>
<th>Dia. (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-Glass</td>
<td>73.8</td>
<td>73.8</td>
<td>30</td>
<td>0.22</td>
<td>2.4</td>
<td>2.25</td>
<td>3.5</td>
<td>10</td>
</tr>
</tbody>
</table>

*Ref: Goa Glass Fibre Limited (Subsidiary of BINANI Industries Limited)

Table 6.2 Mechanical properties of the resin#

<table>
<thead>
<tr>
<th>Matrix</th>
<th>E (GPa)</th>
<th>G (GPa)</th>
<th>$\nu$</th>
<th>$\sigma_{TS}$ (GPa)</th>
<th>$\rho$ (g/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy</td>
<td>3.4</td>
<td>1.27</td>
<td>0.38</td>
<td>0.04</td>
<td>1.18</td>
</tr>
<tr>
<td>Vinylester</td>
<td>3.2</td>
<td>1.1</td>
<td>0.37</td>
<td>0.07</td>
<td>1.03</td>
</tr>
</tbody>
</table>

# Ref: NRC POLYFLEX, Naptha Resins and Chemicals [pvt] Limited
6.3.1 Processing steps

To understand the entire process easily, the major steps performed during the filament winding process are described here.

1. Spool of fiber yarns are kept on the creels.
2. Several yarns from spools are taken and passed through guided pins to the payout eye.
3. Hardener and resin systems are mixed in a container, and then poured into the resin bath.
4. Release agent and gel coat are applied on the mandrel surface and the mandrel is placed between the head and tail stocks of the filament winding machine.
5. Resin-impregnated fibers are pulled from the payout eye and then placed at the starting point on the mandrel surface. Fiber tension is created using a tensioning device.
6. The mandrel and payout eye motions are started. The computer system in the machine creates winding motions to get the desired fiber architecture in the laminate system.
7. Fiber bands are laid down on the mandrel surface. The thickness builds up as the winding progresses.
8. To obtain a smooth surface finish on the outer surface, Teflon coated bleeder or shrink tape is rolled on top of the outer layer after winding is completed.
9. The mandrel with the composite laminate is moved to a separate chamber where the composite is cured at room temperature or elevated temperature.

10. After curing, the mandrel is extracted from the composite part and then reused.

Composite hollow drive shafts were fabricated at the wet filament winding facilities (see Figures 6.4 - 6.7). The fibers were wetted by passing through a resin bath for impregnation just before they were wound onto chrome-plated steel mandrel of 78 mm diameter. Minnelex film was wound over the mandrel to avoid sticking of the shaft to the mandrel and to facilitate easy removal of the shaft. Helical winding process was used to achieve desired angles of $[\pm 30]_{6s}, [\pm 45]_{6s}, [\pm 55]_{6s}, [\pm 75]_{6s}$. The winding tension was 26 N using a built in tensioning mechanism. The tows were wetted using an electrically heated resin bath kept at a maximum temperature of 80ºC. Ceramic eyelets were provided at the entry of fibers in to the resin bath and squeeze rollers at the exit. Four types of specimens were made for each category shafts keeping the angle ply orientations as $\pm 30$, $\pm 45$, $\pm 55$, $\pm 75$ degrees. To avoid fiber slippage along mandrel, pin rings were used at the end of the mandrel. A light source such as an electrode based mercury/vapor bulb (1000watts tungsten filament lamp) was used to deliver the correct UV wavelength energy to initiate the curing action. Teflon-coated air breather was applied on the outer surface to absorb excess resin. Wounded shafts were cured first at 80 ºC for 4h and at 140ºC for another 4h.
After curing, the specimens were extracted from the mandrel and cut to desired length using diamond saw.
Fiber volume content was found out using burn test followed from ASTM D2584 standard and the average fiber volume content found to be 60% for both category shafts. Shafts with a nominal wall thickness of 6mm and fiber angles (relative to axial direction) of $[±30]_6s$, $[±45]_6s$, $[±55]_6s$, $[±75]_6s$ of unidirectional patterns are shown in Figures 6.8 and 6.9.

Figure 6.8 E-Glass/Epoxy shafts of varying stacking sequence

Figure 6.9 E-Glass/Vinylester shafts of varying stacking sequence

Figure 6.10 End fixture made of steel

Figure 6.11 E-Glass/Epoxy shaft with bolted joint
6.4 FABRICATION OF END JOINTS

The sizes of the end joints were selected as circumferential lengths of the two joints were similar to that of the circular joint to give the same adhesive areas. Composite drive shafts with end fixture arrangement are shown in Figures 6.10 and 6.11. In order to hold the shafts, the gripping system suggested in ASTM D2105-09 was adopted. The holes in the flanges of the joints were used to clamp the joints in the torsion tester. The steel adherends of the joints were made of SM45C steel.

6.5 CONCLUSIONS

1. A semi automated filament-winding system, which has been developed, offers potential in the production of filament-wound components of consistent quality. By varying the motor speeds and device movements, different desired path patterns can be obtained, thereby providing flexibility in the winding process.

2. 3-D simulation software was used to get effective solution in the visualization of the filament-winding patterns for cylindrical shaft tubes.

3. Angle-ply shafts of varying sizes and ply angles were successfully fabricated for E-Glass/Epoxy and E-Glass/Vinylester composites. Steel end joints were fabricated and fixed to both ends of the hollow composite shafts.