CHAPTER 5
MEASUREMENT AND TESTING

Measurement and testing were performed in two stages. The measurements performed during experiments were considered as **in-process measurement**, whereas after conducting experiments, they were considered as **post-process measurement and testing.**

Thickness measurement during flow, flow velocity and flow rate measurements were part of in-process measurement. Tensile test, flexural test, cured laminate thickness measurement, microscopic examination, weight measurement, density measurement and measurement of fiber volume fraction (FVF) were part of post-process measurement and testing. Specific tests were performed for specific sets of experiments only. In this section, details of all the measurements and testing methods have been explained.

5.1 IN-PROCESS MEASUREMENT

5.1.1 Measurement of Thickness Variation During Flow

Variation in laminate thickness during flow was measured with dial gauge and front camera. The dial was set to zero before actual impregnation and the camera was used to observe the variation in dial during the actual flow. There were three dial gauges placed with special fixture to measure the variation in part thickness at inlet, middle and outlet during flow. The special fixture was developed shown in Figure 5.1, which was held by glass frame and could be inclined at any angle.

Figure 5.1 Fixture to measure thickness variations during the flow

5.1.2 Resin Flow Velocity Measurement

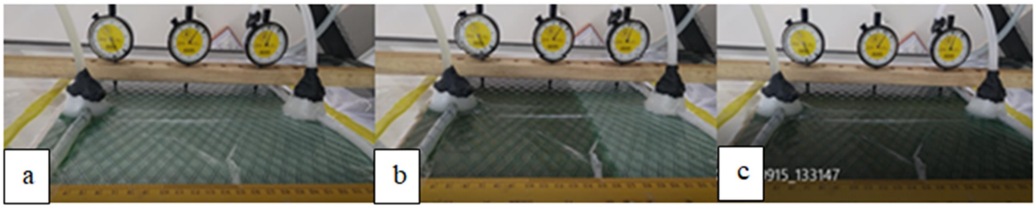

Figure 5.2 Flow velocity and thickness variation measurement a) before b) during c) after impregnation from front camera

Flow velocity was measured during the unsaturated/transient flow by front camera as shown in Figure 5.2. The velocity was measured as time required by resin to reach from supply to vacuum line. A scale was kept along the length of laminate. Front and top camera were used to record distance travelled by resin in a given period of time. The velocity was considered as an average velocity.

5.1.3 Flow Rate Measurement

Flow rate is volume of resin supply in given time. Flow rate measurement was performed to measure the amount of flow moving during unsaturated condition. Flow rate was measured using weighing scale, resin container with volume marked inside the container with gradations

and stop watch. Peristaltic pump was set for particular RPM to control flow rate. Figure 5.3 depicts the method of measurements.

Figure 5.3 Flow rate measurements

5.2 POST-PROCESS MEASUREMENT AND TESTING

5.2.1 Tensile Test

Tensile test was performed as per ASTM D 3039 (for thickness of laminate below 2.5 mm) and ASTM D 638 Type I (for the laminate thickness below 7 mm) and Type II (for the laminate thickness above 7 mm) to measure ultimate tensile strength. It was performed in universal testing machine (TINIUS OLSEN/L-Series H50KL) at speed of 5 mm/minute. Five test coupons were cut from each laminate precisely with vertical blade cutting machine. Laminates were cut and held in universal testing machine as show in Figure 5.4. The tabs were applied for glass tensile test coupons for better gripping.

Figure 5.4 Tensile testing specimens

5.2.2 Flexural Test

Flexural test was performed on laminate as per ASTM D790. Five test coupons were cut from each laminate to get average flexural strength. As per para 7.5 of ASTM D790 span to depth ratio has been selected as 16:1. The three point bending test was performed with keeping minimum overhanging of 10%. Universal tensile testing (TINIUS OLSEN/L-Series H50KL) was used to perform flexural testing with speed of 5 mm/min as shown in the Figure 5.5.

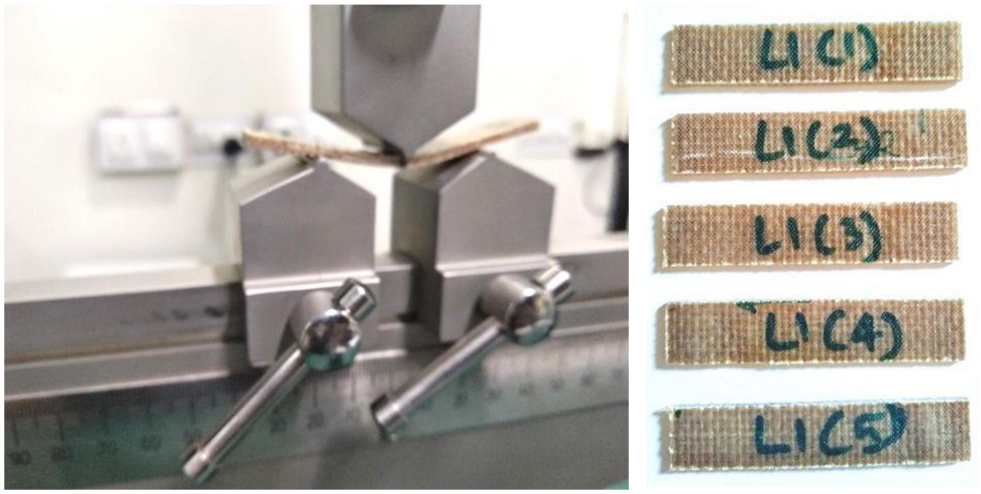

Figure 5.5 Flexural testing specimens

5.2.3 Measurement of Thickness Variation of Cured Laminate

As shown in Figure 5.6, at 25 locations, part thickness was measured with mechanical comparator and variation in part thickness was studied for a laminate. Dial gauge with 0.01 mm least count was used to measure the laminate thickness on flat surface.

Figure 5.6 Measuring laminate thickness with mechanical comparator

5.2.4 Microscopic Examination

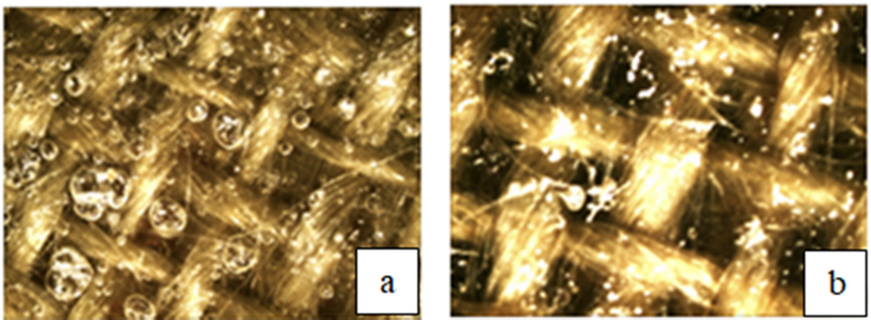

Figure 5.7 Microscopic examinations for jute polyester laminates a) without degassing b) with degassing

Degassing of resin mixture was performed to remove possible air bubbles, which would have generated during the mixture of resin with hardener or due to exothermic reaction. Degassing was performed for polyester resin at full vacuum. Degassing was done for 3 minutes at room temperature after mixing resin with hardener and accelerator. Six micrographs of six laminates, made up of different number of layers with 180X magnification were captured by Nikon SMZ1000 microscope. Figure 5.7 shows micrographs with and without degassing for laminate made up of 5 layers.

5.2.5 Weight Fraction Measurement

Weight fraction was measured in two different ways. For synthetic fibers laminate, loss of ignition method was used, whereas for natural fibers laminate, solvent method was used to measure weight fraction.

5.2.5.1 Weight fraction measurement by Loss of Ignition method (LOI)

The test was performed as per ASTM D 2584 – 94. Three test coupons of size 25 mm X 25 mm were used to perform the test. The test coupons were measured in weighing scale with crucible and weight (w_1) was noted. After this the test coupons were kept at 565 ± 28°C for two hours in muffle furnace. The resin evaporated and the weight of fabric (w_2) was noted after two hours of removing them from furnace. Figure 5.8 shows weight fraction determination by loss of ignition method.

Figure 5.8 Weight fractions measurement by LOI method for glass fabric. a) Weighing of glass laminate b) putting in muffle furnace c) weighing fabric after keeping in furnace for 2 hours at 565 +/- 28° C

5.2.5.2 Weight fraction by solvent method

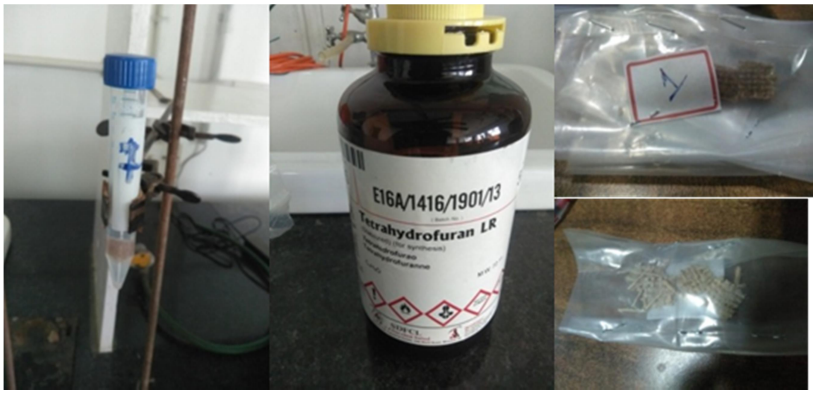

Figure 5.9 Weight fractions measurement by solvent method for jute-polyester laminate

For the laminate prepared by natural fiber, weight fraction cannot be measured using loss of ignition method. There is no standard code available to perform fiber weight fraction for natural fibers. To calculate fiber weight fraction the laminate was dipped inside the THF (Tetra Hydro Furan) solution for 48 hours. The weight of laminate before dipping (w_1) and weight of fabric after removing from solvent (w_2) was measured. It was not very accurate method as some part of resin was stuck on the fabric. Figure 5.9 shows weight fraction measurement by solvent method.

5.2.6 Density Measurement

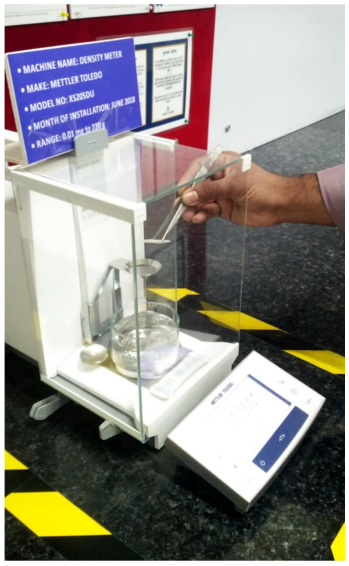

Figure 5.10 Composite density measurements

The density of composite laminate can be determined by dry & wet weight method as per ASTM D792. To measure the density of composite a density measuring kit was used. As shown in Figure 5.10, 25 mm X 25 mm test coupon was cut and weighing of test coupon was done in air and in demineralised water. The density of demineralised water was considered as 0.997 g/cc. The least count of weighing scale was 0.0001 g. The equation used to measure the density of composite laminate was

$$\rho = [A/A-B] * \rho_L \quad \text{(5.1)}$$

ρ = Density of the sample

ρ_L = Density of auxiliary Liquid

A = Weight of the sample in air

B = Weight of the sample in the auxiliary liquid

5.2.7 Fiber Volume Fraction Measurement

Volume fraction can be calculated by rule of mixture method. Let,

Vc = Volume of Composite, Vf = Volume of fiber, Vv = Volume of void

ρc = density of composite (mass/volume), ρf = density of fiber, ρm = density of matrix,

Mf = Mass of fiber, Mc = mass of composite, Mr = Mass of resin

vf = volume fraction of fiber, vm = volume fraction of matrix, vv = volume fraction of void

$$Vc = Vf + Vm + Vv \quad \text{(5.2)}$$

$$1 = \frac{Vf}{Vc} + \frac{Vm}{Vc} + \frac{Vv}{Vc} \quad \text{(5.3)}$$

$$1 = vf + vm + Vv \quad \text{(5.4)}$$

so, volume fraction for fiber can be calculated as, ignoring Vv,

$$Vf = \frac{Mf\ X\ \rho c}{\rho f\ X\ Mc} \quad \text{(5.5)}$$