4. EXPERIMENTAL SETUP AND METHODOLOGY

4.1 Post-process curing of Composite Material

The curing process plays a significant role in accomplishing FRC's mechanical properties and thermal properties. The state of resin (polymer) is liquid (soft) before the fabrication of composite, which then changes to a solid (hard) after curing. For the manufacturing of composite, two types of resins are used (i) primary resin called matrix and (ii) secondary resin called hardener. The condition of matrix changes from liquid to gel and then transforms into solid during cross-linking. Curing can be done at elevated temperatures or at room temperature. Polymer matrix-based composites are post cured at an eminent temperature to boost the amount of cross-linking to attain better chemical and thermal resistance and also better mechanical properties. For suitable post-cure parameters, plates were fabricated and post cured with varying time and temperature in a developed hot air oven. The outcome of post-curing on the mechanical properties of composites has been studied. The fig.4.1 shows developed hot air oven used for post-process curing

Figure 4.1 Developed Hot Air Oven for Post-Process Curing

4.2 In-process curing of Composite Material

An experimental set up of hot plate with temperature controller and sensors with punch and mould (Fig 4.2) was prepared to know the effect of load applied during the fabrication process at controlled temperature (in process curing). A hot air oven was developed for the post-process curing of the specimens. Investigations were made to know the effect of in-process curing and post-process curing on mechanical characterization.

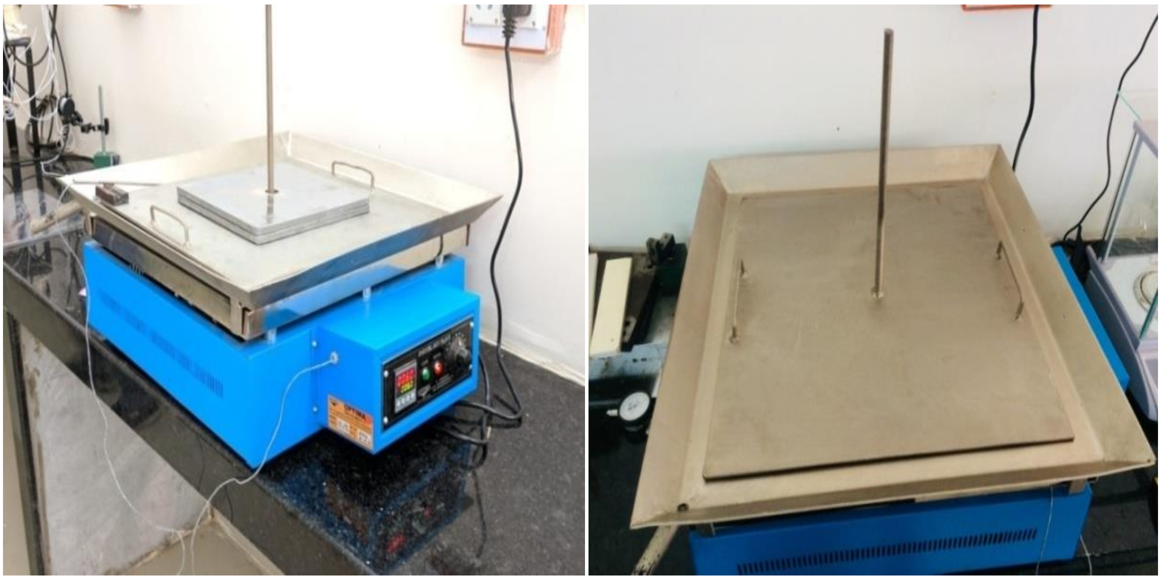


Figure 4.2 Developed Punch and Mould Assembly with Hot Plate for In-Process Curing

The hand layup method was followed in the laboratory for the development of fiber-reinforced polymer composites.

4.3 Preparation of Composite Specimens

Hand Lay-up method was followed by compression to develop composite plates. Detailed procedural steps are as follows,

- Cut weaved fibers into a square piece of size 300mm x 300mm size template.
- There will be four layers of the fibers in the plate, hence measure the weight of four dry square fabric pieces by digital balance meter of least count up to 0.01.
- Prepare resin by adding MEKP (Methyl Ethyl Ketone Peroxide) 2% of resin by weight as a hardener and Cobalt 0.5% by weight as an accelerating agent per 100 ML of resin.
- Clean die and mould with acetone mop to remove dust and dirt from the surface to get a clean and better surface finish.
- Spray mould release sprays on the surface on which plate is to be fabricated three times at the interval of 15 minutes to remove plate easily after cure.
- Apply resin on mould surface and place fiber piece on it. Roll pressure roller on the surface to remove air trapped in the fabric.
- Apply a coat of resin and place another piece of fabric and move the roller to press and remove air bubbles. Repeat the procedure for the remaining layers.

- Put die over the mould and put weight over the die to give required pressure and to drain excess resin from the fabricated plate during the curing process.
- After 24 hours of curing remove the composite plate carefully.
- Measure the weight of the composite plate.
- Measure the thickness of the plate over 25 different points and find out average to get sheet thickness.
- Cut testing sample from the sheet for thermal conductivity measurement, tensile test, and flexural test as per respective ASTM standards.

4.4 Taguchi Method and Analysis of Variance (ANOVA)

In any investigational research, test procedures are normally expensive and time-intense, the need to gratify the design objectives with the smallest number of tests is an important requirement. In this perspective, the Taguchi method provides the investigator with an organized and ingenious approach for conducting tests to establish near-optimal settings of design parameters for performance and cost. This method includes laying out the investigational conditions using specifically constructed tables identified as 'orthogonal arrays'. The use of orthogonal arrays significantly decreases the number of experimental configurations to be studied. The conclusions drained out of small scale experiments are applicable over the entire experimental region spanned by the control factors and their settings. The most significant stage in the design of experiment (DOE) lies in the selection of the process parameters. Therefore, three factors pressure (load), temperature and time are included as process parameters for the tensile and flexural test which are given in Table 4.1 and Table4.2

Table 4.1 Parameter Setting for The Test

Control process parameters	Fixed parameters
Load (Pressure) (N)	Fiber
Temperature (^{o}C)	Resin
Time (Minutes)	Accelerator
	Hardner

Table 4.2 Levels for Various Control Factors

Control Process parameters	**Levels**			**Units**
	I	II	III	
Load (Pressure)	180	230	280	Newton (N)
Temperature	40	60	80	Centigrade ^{0}C
Time	60	120	180	Minutes

The tests are conducted as per the experimental design given in Table 4.3 for a different set of pressure, temperature, and time.

Table 4.3 Combination of the Three Parameters Selected for The Experimentation (L_9 Orthogonal Array)

Sr No	**Load (Pressure) (N)**	**Temperature (^{o}C)**	**Time (Minutes)**
1	180	40	60
2	180	60	120
3	180	80	180
4	230	40	120
5	230	60	180
6	230	80	60
7	280	40	180
8	280	60	60
9	280	80	120

Analysis of variance (ANOVA) is an analysis tool used in statistics that splits an observed collective variability found within a data set into two parts: systematic factors and random factors. The systematic factors have a statistical influence on the given data set, while the random factors do not. ANOVA test is used to determine the influence of load, temperature and time on tensile and flexural strength in a regression study.

4.5 Mechanical Characterisation of Composite Materials

The mechanical characterization is the testing process of checking the mechanical strength of the prepared fiber reinforced polymer plates.

4.5.1 Mechanical Properties

Studies of mechanical properties of composite materials are very significant because most of the application of the material requires mechanical loading. The selection of the composite material under loading is based on tensile strength and flexural strength. Five specimens were selected from each type of plates and values are taken as an average of five specimens.

4.5.1.1 Tensile test

The tensile test determines the ability of the material to withstand the force that tends to pull apart the specimen and the extent to which specimen elongate before breaking. Tensile modulus is a denotation of the relative stiffness of the material and can be established from the slope of the stress-strain plot.

The most frequently used specimen geometries are straight-sided specimens with end tabs and the dog-bone specimen. The test-pieces of mechanical tests were used for dog bone type and having dimensions described as per the ASTM standards. The tension test was performed as per ASTM D638 test standards. The test is repeated five times on five specimens (Refer: tables 4.5, 4.6, and 4.7) made from each type of composite of different pressure, temperature and time combination, and the mean value is reported. The dimensions of the specimen as per standards are shown in fig. 4.3

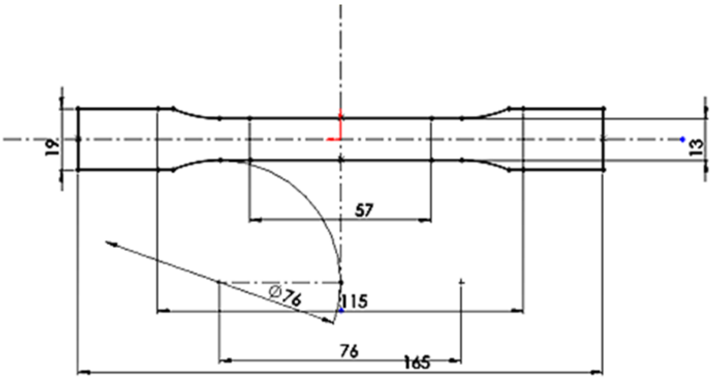


Figure 4.3 Specimen Dimension as per ASTM D638 for Tensile Test

Tensile strength and tensile modulus are determined by numerically as follows.

Tensile strength = Force/ Cross section area =**F/A** **(**Eqn 4.1)

Tensile modulus = Tensile stress/ Tensile strain =$\frac{\mathbf{F/A}}{\boldsymbol{\Delta L/L}}$ (Eqn 4.2)

The tensile strength and tensile modulus of the composites were evaluated with a computerized universal testing machine (Model: TINIUS OLSEN/LSeries H50KL) following the ASTM D638 procedure at a crosshead speed of 5pace/min as shown in fig. 4.4

Figure 4.4 Tensile Testing in The Universal Testing Machine (UTM) (Model: TINIUS OLSEN/LSeries H50KL)

The universal testing machine requires a constant rate of movement. The machine consists of one grip which is in stationary mode and a second grip having movable mode. A load indicating mechanism is capable of indicating the tensile load used with good accuracy. An extensometer is also used to find out the distance between the two points placed within the gauge length of the test sample then the sample got stretched.

4.5.1.2 Procedure for Conducting Tensile test

- The specimen is tightened vertically in the grips of the machine (figure 4.4), it should not slip.
- The dimension of the specimen given to the machine after testing speed is set and the machine is started.
- Specimen start to elongate, resistant of the specimen is recovered by the load cell.
- Elongation of the specimen continued until the breakup occurs.
- Finally, the display of machine shows a value of tensile strength, tensile modulus, stress vs strain curve, elongation, etc.

4.5.1.3 Flexural test

Flexural strength is the capability of the material to withstand the deflecting force applied perpendicular to its longitudinal axis, stiffness of the material can also obtain from this test. The ratio of stress to strain in flexural deformation or a material tends to bend is known as Flexural modulus. It is determined from the slope of a stress-strain curve produced during the flexural test. The determination of flexural strength is an important characterization of any structural material. Usually, a three-point bend test is conducted for finding out this material property. In the present study, specimens of composites were subjected to a flexural test according to ASTM D790 standards.

Flexural strength and flexural modulus (3-point loading system) are determined by numerically as follows. (Varun Mittal, 2016)

$$\text{Flexural strength} = \frac{3FL}{2wh^2} \qquad (\text{Eqn. } 4.3)$$

$$\text{Flexural modulus} = \frac{L^3F}{4wh^3d} \qquad (Eqn\ 4.4)$$

Flexural property of the respective composites is evaluated with computerized Universal Testing Machine (TINIUS OLSEN / LSeries H50KL). Figure4.6). The flexural properties are determined following the ASTM D790 procedure respectively at a crosshead rate of 5 mm/min. The dimension of a flexural specimen as per standards is shown in fig. 4.5 and cut from a composite sheet of the respective material.

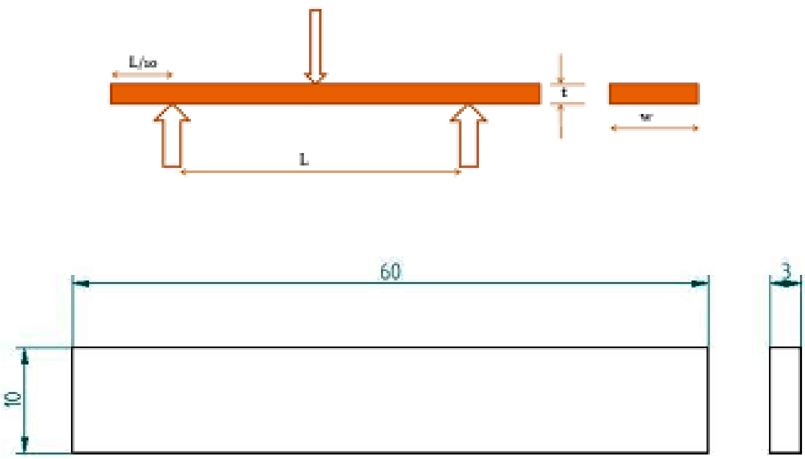


Figure 4.5 Specimen Dimensions as per ASTM D790 for Flexural Test

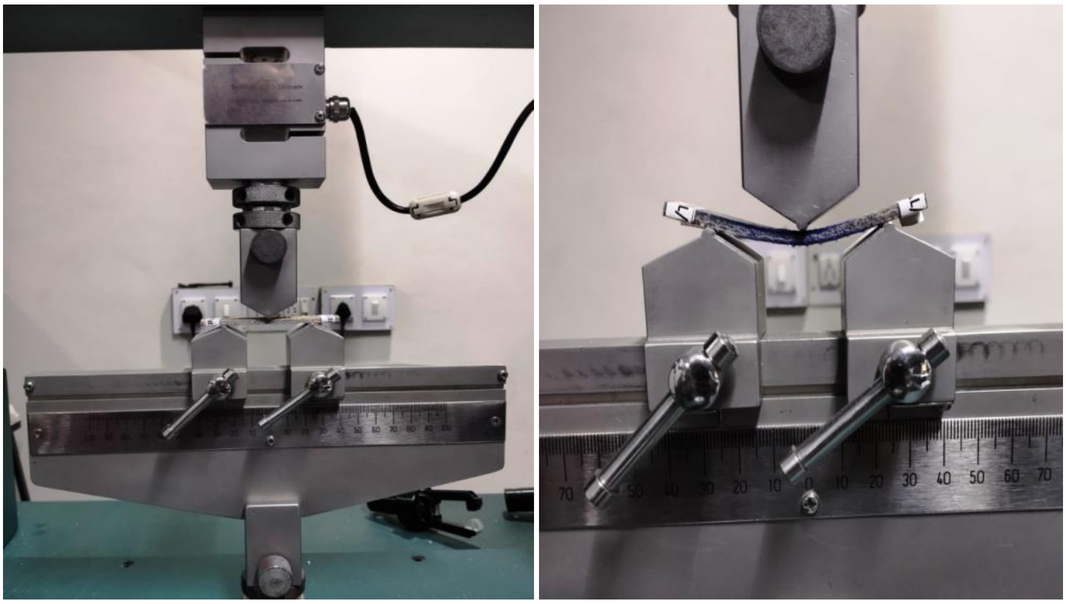


Figure 4.6 Flexural Testing in Universal Testing Machine

4.5.1.4 Procedure for Conducting Flexural test

- In a 3-point flexural test, the area of uniform stress is quite small and concentrated under the center loading point. The specimen bar rests on two supports (fig. 4.6) and loaded employing loading nose midway between the supports.
- Loading nose and the support must have the cylindrical surfaces to avoid the stress concentration.
- The dimension of the specimen given to the respective machine and load is applied to the specimen at the specified speed.
- The specimen starts to deform; the resistance of the specimen is recovered by the load cell.
- The bending of the specimen continued until the breakup occurs.

Finally, the display of the machine shows a value of flexural strength, flexural modulus, Stress vs strain curve etc.

The purpose of this investigation is to find correlations between mechanical strength and the effect of temperature on the curing process during fabrication (in process curing) and a correlation between mechanical strength and effect of temperature after fabrication process with time variable (post-process curing). Different mechanical tests have been carried out as per ASTM standard guidelines.

Composite plates were prepared from jute, basalt, and carbon fibers with vinyl ester as a resin. Plates were prepared in different combination of load, temperature and time (as per Taguchi L9 Orthogonal array) to study the effect of post-process curing on the mechanical strength of the composites whereas to study the effect of in-process curing on mechanical strength, specimens were prepared with a different set of load and temperature. (Refer fig. 4.7)

Figure 4.7 (a) Plate of Carbon-Vinyl Ester Post Cured

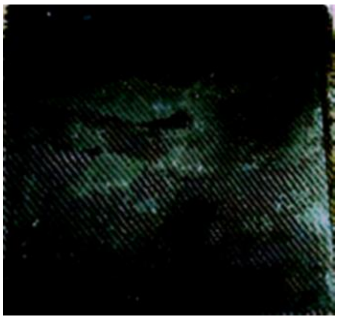


Figure 4.7 (b) Plate of Basalt-Vinyl Ester Post Cured

Figure 4.7 (c) Plate of Jute – Vinyl Ester Post Cured

Table 4.4 Designation of The Codes for Jute –Vinyl ester Composite (JVC) Specimens

TEST	JUTE- VINYLESTER																										
	L	T	t	L	T	t	L	T	t	L	T	t	L	T	t	L	T	t	L	T	t	L	T	t	L	T	t
	180	40	60	180	60	120	180	80	180	230	40	120	230	60	180	230	80	60	280	40	180	280	60	60	280	80	120
TENSILE	JT1804060/1			JT18060120/1			JT18080180/1			JT23040120/1			JT23060180/1			JT2308060/1			JT28040180/1			JT2806060/1			JT28080120/1		
	JT1804060/2			JT18060120/2			JT18080180/2			JT23040120/2			JT23060180/2			JT2308060/2			JT28040180/2			JT2806060/2			JT28080120/2		
	JT1804060/3			JT18060120/3			JT18080180/3			JT23040120/3			JT23060180/3			JT2308060/3			JT28040180/3			JT2806060/3			JT28080120/3		
	JT1804060/4			JT18060120/4			JT18080180/4			JT23040120/4			JT23060180/4			JT2308060/4			JT28040180/4			JT2806060/4			JT28080120/4		
	JT1804060/5			JT18060120/5			JT18080180/5			JT23040120/5			JT23060180/5			JT2308060/5			JT28040180/5			JT2806060/5			JT28080120/5		
FLEXURAL	JF1804060/1			JF18060120/1			JF18080180/1			JF23040120/1			JF23060180/1			JF2308060/1			JF28040180/1			JF2806060/1			JF28080120/1		
	JF1804060/2			JF18060120/2			JF18080180/2			JF23040120/2			JF23060180/2			JF2308060/2			JF28040180/2			JF2806060/2			JF28080120/2		
	JF1804060/3			JF18060120/3			JF18080180/3			JF23040120/3			JF23060180/3			JF2308060/3			JF28040180/3			JF2806060/3			JF28080120/3		
	JF1804060/4			JF18060120/4			JF18080180/4			JF23040120/4			JF23060180/4			JF2308060/4			JF28040180/4			JF2806060/4			JF28080120/4		
	JF1804060/5			JF18060120/5			JF18080180/5			JF23040120/5			JF23060180/5			JF2308060/5			JF28040180/5			JF2806060/5			JF28080120/5		

Abbreviation:

JT- Jute Tensile Test, JF- Jute Flexural Test

Load = 180, 230 and 280 Temperature = 40 C, 60 C,80 C, Time = 60 minutes,120 minute,180 minutes.

Total of 5 specimens of each combination

eg. JT18080180/4 means Jute Tensile test of 180 N load at 80 C temp kept for 180 minutes ...4th specimen amongst total of 5

Table 4.5 Designation of The Codes for Basalt –Vinyl ester Composite (BVC) Specimens

TEST	BASALT - VINYL-ESTER								
	L / T / t	L / T / t	L / T / t	L / T / t	L / T / t	L / T / t	L / T / t	L / T / t	L / T / t
	180 / 40 / 60	180 / 60 / 120	180 / 80 / 180	230 / 40 / 120	230 / 60 / 180	230 / 80 / 60	280 / 40 / 180	280 / 60 / 60	280 / 80 / 120
TENSILE	BT1804060/1	BT18060120/1	BT18080180/1	BT23040120/1	BT23060180/1	BT2308060/1	BT28040180/1	BT2806060/1	BT28080120/1
	BT1804060/2	BT18060120/2	BT18080180/2	BT23040120/2	BT23060180/2	BT2308060/2	BT28040180/2	BT2806060/2	BT28080120/2
	BT1804060/3	BT18060120/3	BT18080180/3	BT23040120/3	BT23060180/3	BT2308060/3	BT28040180/3	BT2806060/3	BT28080120/3
	BT1804060/4	BT18060120/4	BT18080180/4	BT23040120/4	BT23060180/4	BT2308060/4	BT28040180/4	BT2806060/4	BT28080120/4
	BT1804060/5	BT18060120/5	BT18080180/5	BT23040120/5	BT23060180/5	BT2308060/5	BT28040180/5	BT2806060/5	BT28080120/5
FLEXURAL	BF1804060/1	BF18060120/1	BF18080180/1	BF23040120/1	BF23060180/1	BF2308060/1	BF28040180/1	BF2806060/1	BF28080120/1
	BF1804060/2	BF18060120/2	BF18080180/2	BF23040120/2	BF23060180/2	BF2308060/2	BF28040180/2	BF2806060/2	BF28080120/2
	BF1804060/3	BF18060120/3	BF18080180/3	BF23040120/3	BF23060180/3	BF2308060/3	BF28040180/3	BF2806060/3	BF28080120/3
	BF1804060/4	BF18060120/4	BF18080180/4	BF23040120/4	BF23060180/4	BF2308060/4	BF28040180/4	BF2806060/4	BF28080120/4
	BF1804060/5	BF18060120/5	BF18080180/5	BF23040120/5	BF23060180/5	BF2308060/5	BF28040180/5	BF2806060/5	BF28080120/5

Abbreviation:

BT- Basalt Tensile Test, BF- Basalt Flexural Test

Load = 180,230 and 280, Temperature = 40 C, 60 C,80 C, Time = 60 minutes,120 minute,180 minutes.

Total 5 specimens of each combination

Eg. BF18080180/4 means Basalt Flexural test 180 N load at 80 C temp kept for 180 minutes ...4th specimen amongst total of 5

Table 4.6 Designation of The Codes for Carbon –Vinyl ester Composite (CVC) Specimens

TEST	CARBON - VINYL-ESTER																										
	L	T	t	L	T	t	L	T	t	L	T	t	L	T	t	L	T	t	L	T	t	L	T	t	L	T	t
	180	40	60	180	60	120	180	80	180	230	40	120	230	60	180	230	80	60	280	40	180	280	60	60	280	80	120
TENSILE	CT1804060/1			CT18060120/1			CT18080180/1			CT23040120/1			CT23060180/1			CT2308060/1			CT28040180/1			CT2806060/1			CT28080120/1		
	CT1804060/2			CT18060120/2			CT18080180/2			CT23040120/2			CT23060180/2			CT2308060/2			CT28040180/2			CT2806060/2			CT28080120/2		
	CT1804060/3			CT18060120/3			CT18080180/3			CT23040120/3			CT23060180/3			CT2308060/3			CT28040180/3			CT2806060/3			CT28080120/3		
	CT1804060/4			CT18060120/4			CT18080180/4			CT23040120/4			CT23060180/4			CT2308060/4			CT28040180/4			CT2806060/4			CT28080120/4		
	CT1804060/5			CT18060120/5			CT18080180/5			CT23040120/5			CT23060180/5			CT2308060/5			CT28040180/5			CT2806060/5			CT28080120/5		
FLEXURAL	CF1804060/1			CF18060120/1			CF18080180/1			CF23040120/1			CF23060180/1			CF2308060/1			CF28040180/1			CF2806060/1			CF28080120/1		
	CF1804060/2			CF18060120/2			CF18080180/2			CF23040120/2			CF23060180/2			CF2308060/2			CF28040180/2			CF2806060/2			CF28080120/2		
	CF1804060/3			CF18060120/3			CF18080180/3			CF23040120/3			CF23060180/3			CF2308060/3			CF28040180/3			CF2806060/3			CF28080120/3		
	CF1804060/4			CF18060120/4			CF18080180/4			CF23040120/4			CF23060180/4			CF2308060/4			CF28040180/4			CF2806060/4			CF28080120/4		
	CF1804060/5			CF18060120/5			CF18080180/5			CF23040120/5			CF23060180/5			CF2308060/5			CF28040180/5			CF2806060/5			CF28080120/5		

Abbreviation:

CT- Carbon Tensile Test, CF- Carbon Flexural Test,

Load = 180, 230 and 280, Temperature = 40 C, 60 C,80 C, Time = 60 minutes,120 minute,180 minutes.

Total 5 specimens of each combination

Eg. CT18080180/4 means Carbon Tensile test of 180 N load at 80 C temp kept for 180 minutes ...4th specimen amongst total of 5

Hand lay-up process is used to fabricate composite plates in the laboratory as per the details mentioned above in the tables and specimens cut to the size and dimensions for tensile strength and tested as per ASTM D638 standards and for flexural strength, specimens were cut as per ASTM D790 standards(Refer Tables 4.4, 4.5 and 4.6). Five sample specimens were prepared from each plate. (Refer fig. 4.8, 4.9, 4.10 to 4.13)

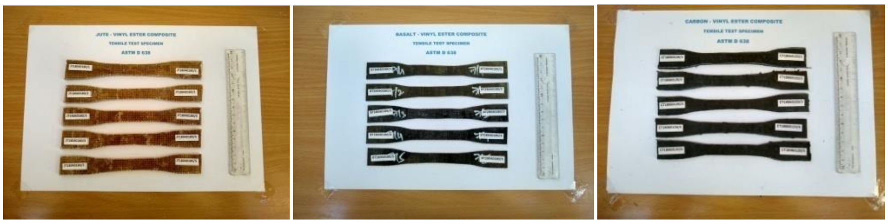


Figure 4.8 Post Cured Specimens of Jute, Basalt and Carbon Fibers with Vinyl Ester as per ASTM D638 for Tensile Tests

Figure 4.9 Specimens of In-Process Curing of Jute Vinyl ester Composite for a Tensile Test as per ASTM D638 Standards

Figure 4.10 (a) Specimens with SiC Filler (b) Specimens with AL Filler (c) Specimens with Cu Filler

Figure 4.11 Post Cured Specimens of Jute, Basalt and Carbon Fibers with Vinyl Ester as per ASTM D790 for Flexural Test

Figure 4.12 Specimens of In-Process Curing Jute-Vinyl Ester Composite as per ASTM D790 for Flexural Test

Figure 4.13 (a) Specimens with SiC Filler (B) Specimen with Cu Filler(C) Specimen with Al Filler as per ASTM D790 for Flexural Tests

4.6 Thermal Characterisation

The heat conduction depends on thermal transport property called thermal conductivity. The measured numerical value of thermal conductivity gives an idea about the use of the material as a heat conductor or insulator. To measure the thermal conductivity of materials for a wide range of temperatures, a laboratory model was developed which works based on Guarded Hot

Plate using the principle of a calorimeter. Experiments were performed for measuring the thermal conductivity of jute-polyester composites (with filler and without filler) also of hybrid composites of bamboo and glass fibers with vinyl ester over a limited range of temperature. By adding highly conductive fillers in composite polymer we can achieve significant improvement in thermal conductivity without major effect on mechanical properties. Experiments are conducted to measure the thermal conductivity of different specimens of composite fabricated by adding different conductive filler materials during the fabrication process.

4.7 Development of Apparatus for Measuring Thermal Conductivity based on GHP Method using Calorimeter principle

The guarded hot plate is a standard technique for measuring thermal conductivity (low range) of solid materials. Insulation materials and mid-range conductors as well maybe tested by GHP method and many laboratories and organizations have developed their apparatuses based on this method. The device is developed in this research is based on a single specimen type of guarded hot plate apparatus.

4.7.1 Components and Materials

4.7.1.1 Hot Plate – It is made of aluminium in the form of cylindrical plates in two halves; of which the lower thinner cylinder is 10mm and the upper cylinder is 18mm thick. A square slot of 80mm is cut at the center in both plates in such a way that recess of 8mm total depth is formed when both the parts are bought together. The heater is sandwiched between two halves in this recess. Aluminium plates are electrically insulated from the electric circuit by a thin layer of thermal adhesive. For the temperature measuring sensor, a hole of 4mm diameter and 40mm length is drilled on the peripheral wall of the upper plate 3mm below the top surface (fig..4.14)

The hot plates and the heater are clamped and bolted together as to restrict the lateral movement between the two.

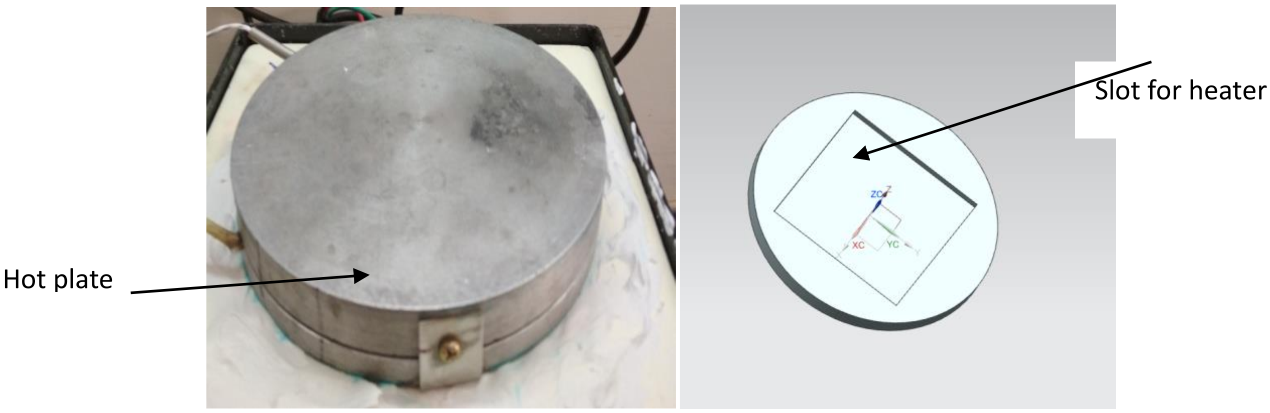


Figure 4.14 Hot Plate

4.7.1.2 Cold Plate Assembly – It is also made from aluminium with cylindrical base plate 10mm thick together with coolant tank above in one piece. The thickness of the tank wall is 6mm and its height from the base plate is 70mm. A hole for the sensor of diameter 4mm and 40mm length is drilled on the peripheral wall of the base plate in radial direction 3mm above the bottom surface. Two holes, one just above the base plate and other 5mm from the top are drilled for coolant inlet and outlet connections respectively (fig.4.15).

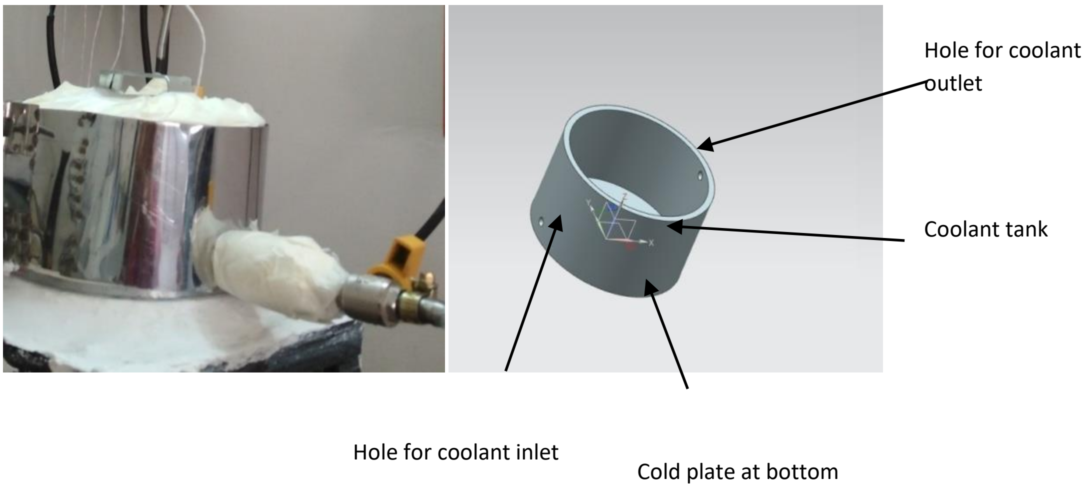


Figure 4.15 Cold Plate

To get the isothermal conditions both the plates are made of good conducting material aluminium which also has good machinability. The plates and other components used in the apparatus are rated at high temperatures to satisfy the demands. Materials selected for heater and plates are dimensionally and chemically stable in the operating temperature range. The heat capacity of the hot plate affects the time required to reach the steady-state. The thick plates help in reducing lateral temperature distributions but reduce responsiveness. So thickness is selected as to balance these requirements.

Here thermal steady-state said to achieve when the temperature of the plates and coolant does not vary with time. This varies considerably with the apparatus design, specimen to be measured, and test conditions.

4.7.1.3 Heater Plate – It is an S.S.-mica type strip heater made up of several layers. The heating wire used is kanthol of gauge 20 wrapped on and covered with mica. It is of 1kW rating (fig.4.16).

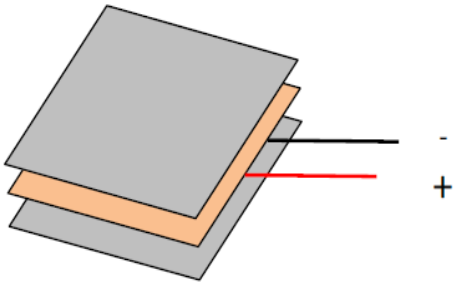


Figure 4.16 Heater

4.7.1.4 Overhead Tank – It is a tank at an appropriate height for storing coolant is required as to supply it at constant head and temperature and act as a heat sink.

4.7.1.5 Coolant Inlet and Outlet Valves – They are made of brass of size 1/4" are connected at the inlet and outlet ports for flow regulation.

Figure 4.17 Control/Display Unit

4.7.1.6 Control/Display Unit – Following are the main components of Control/Display unit (fig 4.17)

Temperature Sensors – They are for measuring the temperature at different locations, resistance temperature detector (RTD) of type PT100 properly calibrated using a certified thermometer are installed. Sensors S1, S2, S3, and S4 are used to get the temperature of a hot plate, cold plate, coolant inlet, and coolant outlet respectively. The probe is 40mm long of diameter 4mm made of S.S. They must be in good contact with the plates. So epoxy is used as a contact medium to reduce its thermal contact resistance with the plates. The fine wire of 0.2mm thickness is used in the making of the sensor. The Teflon insulated wires used do not come in contact with the plates as sensors are installed on the outer peripheral wall of the plates so there is no heat flow along with them. This is to get the correct plate temperature and reduce the error in measurement. The wires for the heater sensor and heater are connected to the solid-state relay and terminal block and then connected to the power supply and display unit.

Temperature Indicator – It is a digital type. The electrical signals from the temperature sensors are converted to temperature unit using a mathematical equation based on the sensor's calibration curve or an appropriate reference. The specifications are as below:

Table 4.7: Specification of Temperature Indicator

Model	**Multi-Span Model MDI38**
Supply	230V AC ± 10%, 50Hz
Input	PT-100/3W (RTD)
Range	0°C -200.0 °C
Display	4-Digit, 0.8 inch, Red colour

The specifications of the temperature controller are as below:

Table 4.8 Specification of Temperature Controller

Model	**Multi-span PID temperature controller Model UTC 121P**
Display	Upper: 4 digit, 0.56”, Red LED Display Lower: 4 digit, 0.4”,Green LED Display
Input	J, K, PT-100 (selectable)
Temperature Range	PT-100: -99°C to 400 °C
Control Action	PID/ON-OFF (selectable)
Power Supply	100 to 250V AC, 50/60 Hz, Approximately 4VA

4.7.1.7 Assembly of Hot and Cold Plate

Two aluminium plates with the same dimension of the specimen are placed on either side of the specimen to create a uniform heating profile and prevent any convective thermal loss directly from the sample to the environment. A heater is sandwiched and fitted in the inbuilt groove made in the two halves of the hot aluminium plate.

The coolant tank of the cold plate assembly with valve operated inlet and outlet ports is affixed on the hot plate to make the heat flow vertically in an upward direction through the specimen sandwiched in between the hot plate and the cold plate assembly. The coolant is made to flow in the coolant tank as to sustain the upward heat flow.

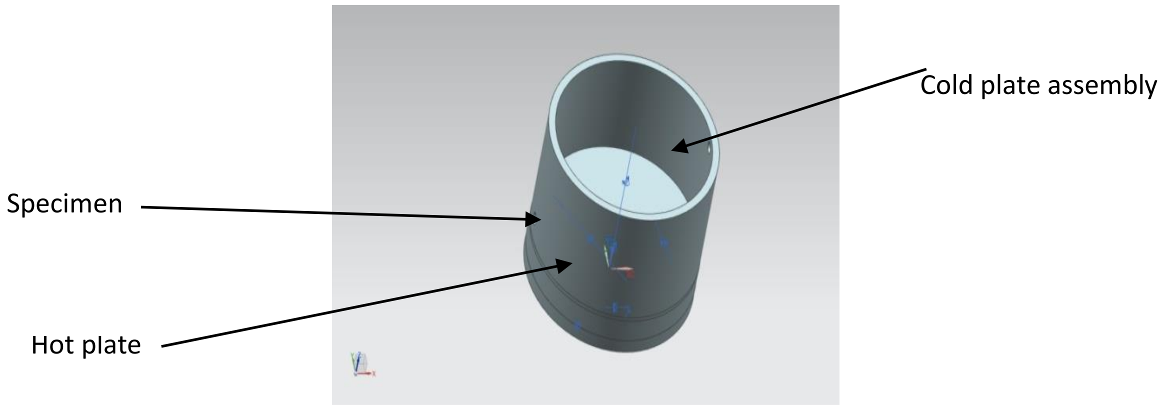


Figure 4.18: Assembly of a Hot Plate and Cold Plate

Resistance Temperature Detector PT 100 type sensors are installed for measuring the temperature of the plates, coolant inlet, and outlet. These sensors are installed by drilling the holes of adequate size on the peripheral surface of the plates as described above.

The whole of the cold plate assembly is insulated by a layer of ceramic wool packed beneath the S.S. sheet to prevent the heat loss and to assure one-dimensional heat flow. Hot plate and hence the whole assembly is made to rest on the tripod supporting stand with a bowl that has a layer of insulation on the inside wall that envelops the hot plate to prevent the heat loss. This restricts the edge heat loss which is normally the source of greatest measurement errors. The bottom face of the hot plate is insulated with calcium silicate plate and plaster of paris for protecting from backward heat loss.

4.7.1.8 Experimental set up Developed for Measuring Thermal conductivity

The hot plate and cold plate surface should remain straight during the experimentation process of the apparatus. Also, the surface of the specimen should be such that they are parallel and have uniform thermal contact with the two plates. It is necessary to smooth the specimen surfaces to have a better plate to specimen contact. This is to be ensured because the measured heat flux will be greater than the heat flux obtained in the absence of voids if the apparent thermal conductivity of the contact void is greater than that of the specimen. The weight of the cold plate assembly here acts as the inertia force to maintain accurate spacing and have good thermal contact between the hot and cold plates (fig.4.19 and fig 4.20).

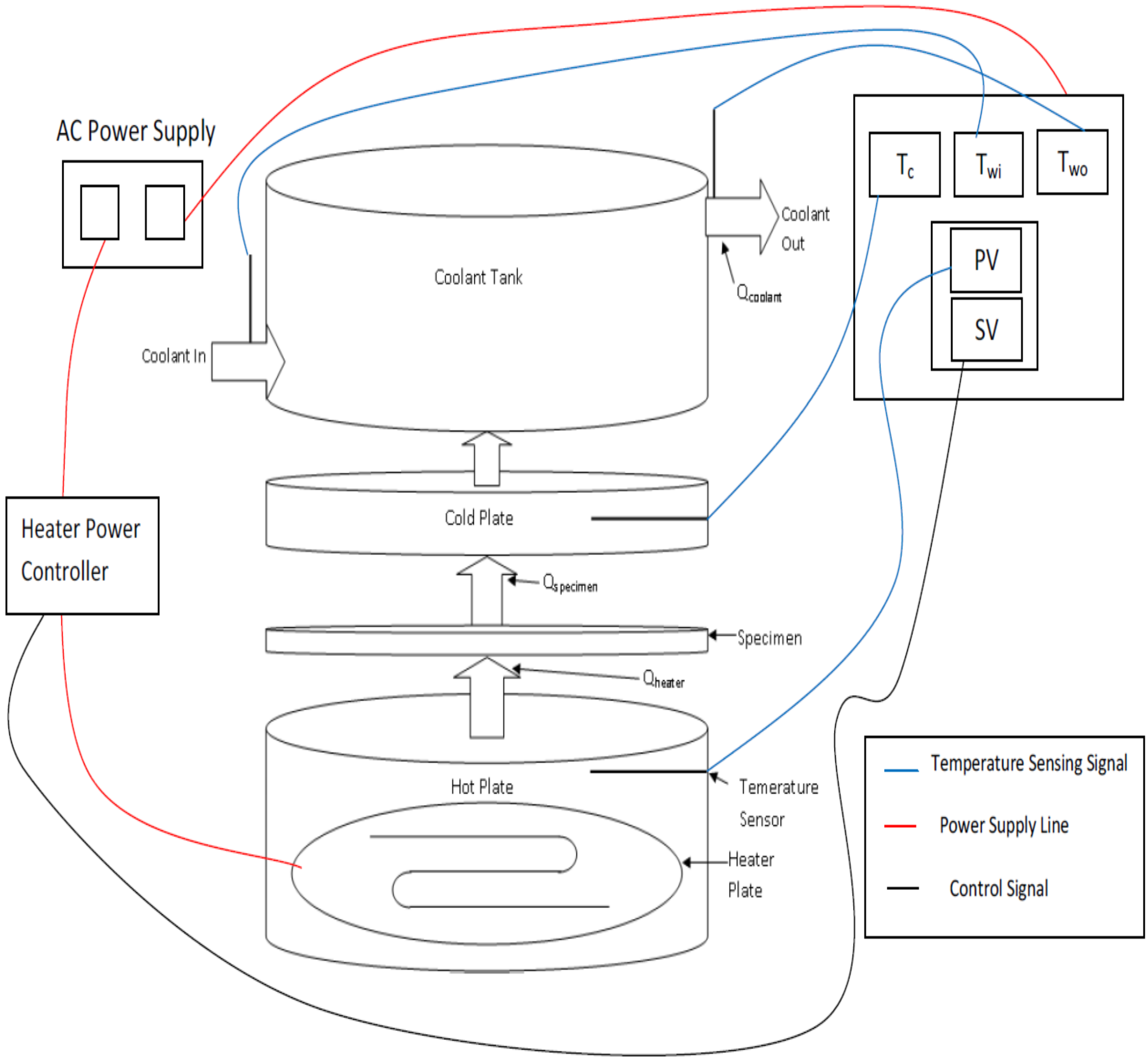


Figure 4.19: Schematic Diagram of the Developed Experimental Setup for Measuring Thermal Conductivity

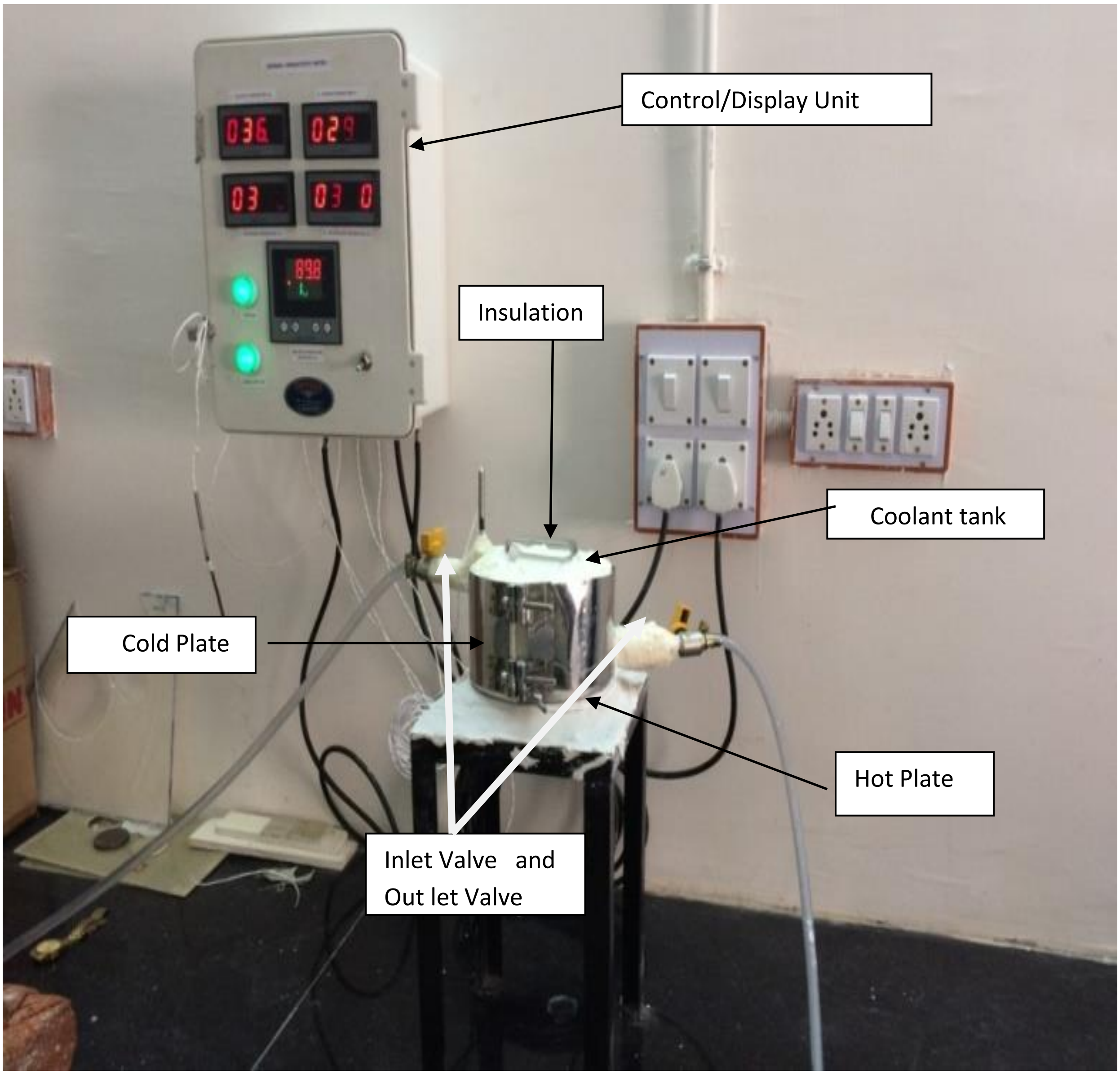


Figure 4.20 Developed Experimental Set Up for Measuring Thermal Conductivity

The specimen size of 50.8mm diameter and 0.5 to 25.4mm thick can be selected as per ASTM C1530. The composite specimens were prepared by hand layup technique (fig. 4.21 and fig 4.22)

4.7.2 Experimental Methodology

The water is used as a coolant which is filled and flown through the coolant tank. The heater heats hot plate at the required temperature set through the controller. The heat transfers through the circular disc-shaped specimen placed on a hot plate by mode of conduction. The peripheral surface of the hot plate is covered by insulation to restrict heat loss and to make heat flow through the specimen only. The heat is conducted to the cold plate assembly from the specimen which in turn raises the temperature of the coolant in the tank which is sensed by the sensor placed at the outlet. The sensors are also used to measure the temperature of the hot plate, cold plate, and the coolant inlet as described above.

Initially, the temperature keeps on increasing, and reading is to be noted when the steady-state condition is reached. (temperature almost remains constant concerning time). Based on the temperature difference of the coolant of inlet and outlet and the coolant flow rate, the heat absorbed by the water can be known. Knowing the temperature of the hot plate and cold plate, the thermal conductivity of the specimen can be calculated using Fourier’s law of heat conduction assuming no heat loss.

The stepwise procedure is described below:

- Measure and record the specimen dimensions.
- Place the specimen in the developed experimental setup.
- Insulate required surfaces properly.
- Switch ON the power switch of the developed experimental setup.
- Open the inlet valve of the coolant tank and manage and fix the coolant flow rate.
- Switch ON the heater.
- Set the desired temperature with the controller and adjust the power input to the heater.
- For taking readings, wait for a reasonable time till the temperature of the plates become fairly constant with time, that is, a steady-state is reached.
- Read the cold plate temperature on the digital temperature indicator.
- Read inlet and outlet temperatures of the coolant in the coolant tank.
- Measure the cooling water flow rate using a measuring tank and stopwatch.
- Using the measured temperatures, water flow rate and the dimension of the specimen, the heat flow rate and thermal conductivity of the specimen can be calculated.
- Upon completion of the test, remove the specimen and check its thickness to ensure that it is not changed from the initial condition.
- A thermal steady state must be achieved for this method to be valid. The temperatures of the hot and cold surfaces have to be stable during the test.

The heat absorbed by the flowing coolant (water) is given by the equation as under

$$Q = m_w . c_{pw} . (t_{wo} - t_{wi}) \quad \text{(Eqn No 4.5)}$$

Fourier's law of heat conduction:

The thermal conductivity of the specimen material being tested is calculated using Fourier's Law of heat conduction as

$$Q = k_s \times A_s \times \frac{(T_h - T_c)}{L_s} \quad \text{(Eqn No. 4.6)}$$

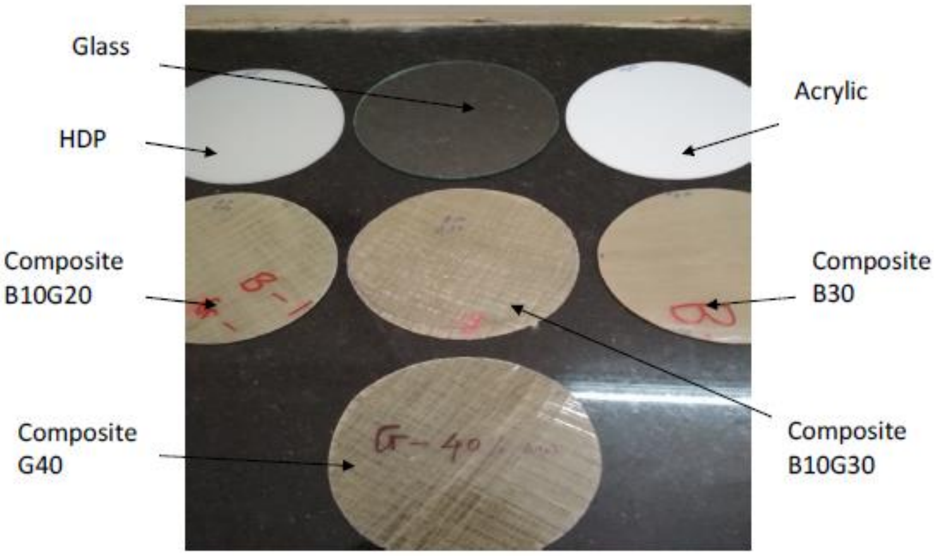
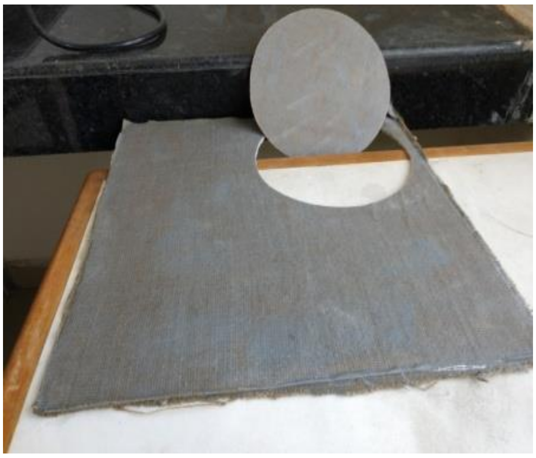


Figure 4.21 Specimens Prepared for Thermal Conductivity Measurement (as per ASTM C1530) of Different Combination of Bamboo and Glass Fibers

Composite plates with filler are fabricated by hand lay-up process using jute fibers. Filler powder (20gms) is added during the fabrication process. Jute- Polyester composite plates with different fillers are shown in figure 4,22 below.

(a) With Cu Filler

(b) With SiC filler



(c) With Al Filler

Figure 4.22 Specimen for Testing Thermal Conductivity of Jute-Polyester Composite as per ASTM C1530