4.1 INTRODUCTION

The composite materials are inhomogeneous and anisotropic, and their behaviour under load is more complicated than that of homogeneous and isotropic materials such as metals. The main reasons for this are the different types of damage that can occur, their interaction and their different growth rates. Among the parameters that influence the performance of composites are [172];

- Fiber type: Glass, Carbon, aramid, metal, etc.
- Matrix type: Thermosetting or thermoplastic resin,
- Reinforcement structure: Unidirectional, fabric, three directional, etc.
- Stacking sequence: Symmetric, asymmetric, angle ply, cross ply, etc.
- Environmental conditions: temperature, moisture, etc.
- Loading type and boundary conditions.

4.2 EXPERIMENTAL MATERIALS

4.2.1 Matrix Material

Among the polymeric matrices, the thermoset epoxy resins are widely used in industries, because of their mechanical strength, chemical resistance, corrosion resistance, fatigue strength, service temperature requirements, strength-to-weight and stiffness-to-weight ratios. The epoxy resin also allows modifications in its chemical structure depending on the required application [80,81].

Epoxies generally out-perform most other resin types in terms of mechanical properties and resistance to environmental degradation, which leads to their almost exclusive use in aircraft and marine industries. As a laminating resin their increased adhesive properties and resistance to water degradation make these resins ideal for use in applications such as boat building. The term epoxy refers to a chemical group consisting of an oxygen atom bonded to two carbon atoms that are already bonded in some way. The simplest epoxy is a three-member ring structure known by the term ‘alpha-epoxy’ or
'1,2-epoxy'. The idealized chemical structure is shown in the Fig. 4.1 below and is the most easily identified characteristic of any more complex epoxy molecule.

\[
\text{CH}_2 - 
\begin{array}{c}
\text{CH} \\
\end{array}
\text{- O}
\]

Fig. 4.1 Chemical Structure of a Simple Epoxy (Ethylene Oxide).

Usually identifiable by their characteristic amber or brown colour, epoxy resins have number of useful properties. Both the liquid resin and the curing agents form low viscosity easily processed systems. Epoxy resins are quickly and easily cured at any temperature from 5°C to 150°C, depending on the choice of curing agent. One of the most advantageous properties of epoxies is their low shrinkage during cure that minimizes fabric print-through and internal stresses. High electrical insulation and good chemical resistance also enhance high adhesive strength and high mechanical properties. Epoxies find uses as adhesives, caulking compounds, casting compounds, sealants, varnishes and paints, as well as laminating resins for a variety of industrial applications [158].

Epoxy resins are formed from a long chain molecular structure similar to vinyl-ester with reactive sites at either end. In the epoxy resin, however, these reactive sites are formed by epoxy groups instead of ester groups. The absence of ester groups means that the epoxy resin has particularly good water resistance. The epoxy molecule also contains two ring groups at its centre that are able to absorb both mechanical and thermal stresses better than linear groups and therefore give the epoxy resin very good stiffness, toughness and heat resistant properties. The Fig. 4.2 shows the idealized chemical structure of a typical epoxy, known as Diglycidol Ether of Bisphenyl-A (DGEBA).

\[
\text{CH}_3
\begin{array}{c}
\text{- CH} \\
\end{array}
\text{- CH}_2\text{- CH}_2\text{- CH}_3
\]

Fig. 4.2 Chemical Structure of a Typical Epoxy (Diglycidol Ether of Bisphenyl-A).
Bisphenyl-A is produced by reacting phenol with acetone under suitable conditions. The "A" stands for acetone, phenyl means phenol groups and bis means two. Thus, bisphenyl-A is the chemical product made from chemically combining two phenols with one acetone. Un-reacted acetone and phenol are stripped from the bisphenyl-A which is then reacted with a material called epichlorohydrin. This reaction sticks the two (di) glycidol groups on ends of the bisphenyl-A molecule. The resultant product is the diglycidol ether of bisphenyl-A, or the basic epoxy resin. These glycidol groups react with the amine hydrogen atoms or hardeners to produce the cured epoxy resin. Epoxy hardeners are not catalysts. Catalysts promote reactions but do not chemically become a part of the finished product. Epoxy hardeners mate with the epoxy resin, greatly contributing to the ultimate properties of the cured system [167].

Epoxy resins differ from polyester resins, for curing epoxies a hardener is required rather than a catalyst. The hardener, often an amine, is used to cure the epoxy by an ‘addition reaction’ where both materials take place in the chemical reaction. The chemistry of this reaction means that there are usually two epoxy sites binding to each amine site. This forms a complex three-dimensional molecular structure that is illustrated in Fig. 4.3.

Fig. 4.3 Schematic Representation of Epoxy Resin (Cured 3-D Structure).

Since the amine molecules ‘co-react’ with the epoxy molecules in a fixed ratio, it is essential that the correct mix ratio be obtained between resin and hardener to ensure that a complete reaction takes place. If amine and epoxy are not mixed in the correct ratios, un-reacted resin or hardener will remain within the matrix which will affect the final properties after cure. To assist with the accurate mixing of the resin and hardener, manufacturers usually formulate the components to give a simple mix ratio which is easily achieved by measuring out by weight or volume [158].
Hardeners used with room temperature cured epoxy resins are most commonly polyamines. That is, they are organic molecules containing two or more amine groups. Amine groups are not unlike ammonia in structure except that they are attached to organic molecules. Like ammonia, amines are strongly alkaline. Because of this similarity, epoxy resin hardeners often have an ammonia-like odour, most notable in the dead air space in containers right after they are opened. Reactive amine groups are nitrogen atoms with one or two hydrogen atoms attached to the nitrogen. These hydrogen atoms react with oxygen atoms from glycidol groups on the epoxy to form the cured resin a highly cross-linked thermoset plastic. The three dimensional structure gives the cured resin excellent physical properties. The ratio of the glycidol oxygen to the amine hydrogen, taking into account the various molecular weights and densities involved, determines the final resin to hardener ratio. Varying the recommended ratio will leave either un-reacted oxygen or hydrogen atom depending upon which side is in excess. The resultant cured resin will have lower strength as it is not as completely cross-linked. All hardeners are mixtures of aliphatic polyamines, cycloaliphatic polyamines and/or amido amines.

Cure time of an epoxy system is dependent upon the reactivity of the amine hydrogen atoms. While the attached organic molecule takes no direct part in the chemical reaction, it does influence how readily the amine hydrogen atoms leave the nitrogen and react with the glycidol oxygen atom. Thus, cure time is set by the kinetics of the particular amine used in the hardener. Cure time can be altered only by selecting a different hardener, adding an accelerator in systems that can accommodate one, or by changing the temperature and mass of the resin/hardener mix. The epoxy curing reaction is exothermic. This means that it gives off heat as it cures. The rate at which the epoxy resin cures is dependent upon the curing temperature. The warmer it is the faster it cures. The curing rate will vary by about half or double with each 18°F (10°C) change in temperature. Pot life and working time are greatly influenced by the initial temperature of the mixed resin and hardener. The gel time of the resin is the time it takes for a given mass held in a compact volume to solidify. Gel time depends on the initial temperature of the mass, the curing rate of an epoxy is dependent upon the curing temperature, while the curing mechanism is independent of temperature. The reaction proceeds most quickly in the liquid state. As the cure proceeds the system changes from a liquid to a sticky viscous soft gel. After gelation the reaction speed slows down as hardness increases.
Chemical reactions proceed more slowly in the solid state. From the soft sticky gel the system gets harder, slowly losing its stickiness. It becomes tack free and continues to become harder and stronger as time passes. At normal temperatures the system will reach about 60 to 80% of ultimate strength after 24 hours. Curing then proceeds slowly, finally reaching a point where no further curing will occur [167].

The epoxy matrix material used in this research work is a commercial grade epoxy obtained from Ciba-Geigy limited, India. Araldite LY556 is an unfilled non-modified epoxy resin of low viscosity for the laying up of laminates, which may be converted to the solid, infusible state with hardener. The choice of hardener is governed by the curing temperature, pot life and heat resistance required, as well as by the application method used. The viscosity of the resin has significant effect on the method of application, hence diluents are used to control the resin viscosity. Hardener HY951 an aliphatic primary amine is used if curing is to take place at room temperature or with in a shorter time, at 50° to 120° C. Araldite LY556 forms a solid bond with the reinforcement surface during curing, thereby allowing the preparation of high grade laminates without finishing operation.

The mixing of epoxy and hardener should be in the specified ratio, for every 100 parts of epoxy 10-12 parts of hardener is mixed. The LY556 and HY951 combination gives laminate with excellent water resistance and very low cure shrinkage, hence the laminates of this epoxy are dimensionally stable and practically free from internal stresses. Properties of the cured neat epoxy are listed in Table 4.1 and if desired these resins also can be coloured using colouring pastes, depending upon the requirement whole laminate may be coloured or only the top ply may be coloured [28,159].

<table>
<thead>
<tr>
<th>Density, Kg/m³</th>
<th>Tensile Strength, MPa</th>
<th>Tensile Modulus, GPa</th>
<th>Elongation, %</th>
<th>Flexural Strength, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200-1250</td>
<td>83-93</td>
<td>31-33</td>
<td>4.2-5.6</td>
<td>115-125</td>
</tr>
</tbody>
</table>

4.2.2 Reinforcement Materials

Hybridization of composites provide many advantages over usual composite materials, one of the major advantage is that it improves the damage resistance of composites.
Therefore in this research work with an aim to fabricate interply hybrid composite material two types of reinforcements are selected, one is glass fabric and the other is textile satin cloth [3,148,159].

4.2.2.1 Glass Fabric
Glass as a structural material was introduced early in the seventeenth century and became widely used during the twentieth century as the technology for flat pane was perfected. Glass fibrous usage for reinforcement was pioneered in replacement of metals with the advent of continuous filaments. These events lead to a wide range of aerospace and commercial high performance structural applications still in use today [114].

Glass fibers account for over 90% of the fibers used in reinforced plastics because they are inexpensive to produce and have relatively good strength to weight characteristics. Additionally, glass fibers exhibit good chemical resistance and processability. The excellent tensile strength of glass fibers, however, may deteriorate when loads are applied for long periods of time. Continuous glass fibers are formed by extruding molten glass to filament diameters between 5 and 35 μm. Individual filaments are coated with a sizing to reduce abrasion and then combined into a strand of either 102 or 204 filaments. The sizing acts as a coupling agent during resin impregnation.

Glass is derived from one of our most abundant natural resources; sand. Raw materials such as silicates, soda, clay, limestone, boric acid, fluorspar or various metallic oxides are blended to form a glass batch that is melted in a furnace and refined during lateral flow to the fore hearth. The molten glass flows to platinum/rhodium alloy bushings and then through individual bushing tips and orifices ranging from 0.76 to 2.03 mm and is rapidly quenched and attenuated in air (to prevent crystallization) into fine fibers ranging from 3 to 35 μm. Mechanical winders pull the fibers at linear velocities up to 61m/s over an applicator which coats the fibers with an appropriate chemical sizing to aid further processing and performance of the end products. Several types of silicate glass fibers are manufactured for the textile and composite industry, hence based on their chemical composition, properties and functionality they are termed as A, C, D, E, R and S glass.
E-Glass (lime-alumina-borosilicate) found adaptable and highly effective in a great variety of processes and products ranging from decorative to structural applications and it has become standard textile glass. E-glass is the most common reinforcement in composite structural applications which exhibits excellent strength, modulus, resistance to water degradation and corrosive environments, durability, good fatigue life and it is easily available and cheaper. In order to produce hybrid composite laminates, Plain weave E-glass fabric is used as the first reinforcement material. The candidate material has areal density range between 110-122gsm, with 4 mil fabric and the fibers in wrap and fill directions being 60 X 58 respectively per inch length. The composition of the E-glass fabric is presented in Table 4.2, while the properties are shown in Table 4.3.

### Table 4.2 Composition of E-glass in percentage

<table>
<thead>
<tr>
<th></th>
<th>SiO2</th>
<th>Al2O3</th>
<th>CaO</th>
<th>MgO</th>
<th>B2O3</th>
<th>K2O</th>
<th>Na2O</th>
<th>Fe2O3</th>
<th>TiO2</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>52-56</td>
<td>12-16</td>
<td>16-25</td>
<td>0-5</td>
<td>8-13</td>
<td>0-1.5</td>
<td>0-1.5</td>
<td>0.05-0.4</td>
<td>0-0.8</td>
<td>0-0.5</td>
</tr>
</tbody>
</table>

### Table 4.3 Properties of E-glass

<table>
<thead>
<tr>
<th>Density, Kg/m³</th>
<th>Tensile Strength, MPa</th>
<th>Tensile Modulus, GPa</th>
<th>Elongation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500-2550</td>
<td>3400-3600</td>
<td>72-75</td>
<td>4.2-4.8</td>
</tr>
</tbody>
</table>

4.2.2.2 Satin Cloth

Satin is a type of glossy fabric supposedly originated in Zaytoun, China, which is now Canton. It became popular in Europe in the 12th century, in Italy in the 13th century and in England in the 14th century. Satin, because of its construction, high gloss and fiber content is one of the most luxurious fabrics and the choice of royalty for both their feel and sheen. Satin is most often made from low twist, filament yarns. It is usually constructed by floating the warp or lengthwise yarns over filling or horizontal yarns. The long floats give the fabric luster [88, 104,105].

Traditional satin has a glossy and a dull side. While satin was once made exclusively of silk, since silk satins are more expensive hence satin is now made with polyester, acetate, nylon, cotton and rayon. These other fabrics provide a less expensive means to achieve the glossy finish provided by satin. Shine from satin is derived through
its weave. Some weft or weave yarns are brought to the surface in a process called floating, which allows some of the yarn to reflect light, thus producing the shine and gloss. In some cases, it is possible to achieve this effect on both sides of a garment, producing double-faced satin. This material is often highly desirable, since it is soft against the skin, but will tend to cost more, particularly if made with silk. There are several types of satin, which can vary in thickness, flexibility, and weight [104].

**Crepeback Satin:** Crepe yarns or highly twisted yarns are used in the filling direction of the fabric and the smooth low-twisted filament yarns are still used in the warp.

**Antique Satin:** This type of satin is created using slub (yarns with thick and thin areas) yarns in the filling direction.

**Duchesse Satin:** A high yarn count satin that contains fine yarns hence fairly stiff and glossy on one side. This type of satin has a crisp body to it.

**Satin faconne** or satin jacquard is a type of satin with patterns woven through it. These could be stripes, paisley, or virtually any design. Satin jacquard comes in a variety of weights and qualities, but tends toward being a looser more flexible fabric than duchess.

**Slipper Satin:** A heavy stiff satin used mainly for footwear.

**Delustered satin,** also called *peau de soie* (skin of silk), is a less shiny, lightweight material. Unlike the shine associated with other forms of satin, *peau de soie* is often described as having a dull luster. Delustered satin is usually finished on both sides, making it double-faced. One can also note fine-grained threads in this type of satin.

**Sateen:** Sateen is a glossy cloth made from cotton or rayon. Sateen starts with long-fiber, combed or carded cotton. The cotton is then mercerized to bring out sheen. Mercerization involves soaking the fiber in a bath of sodium hydroxide and then in an acid bath. The result makes the cotton fiber stronger and more easily dyed. It also adds a luster to the fibers. Sateen should be very soft to the touch, with a high thread count and should drape well. Sateen fabric uses the satin stitch in construction, which means the threads are mostly on one side of the fabric, giving that smooth look. Sateen has been a popular fabric and being made of cotton, it is much cheaper than silk satin and is also more durable.
In this research, the second reinforced fabric is cotton satin (sateen). The composition of the typical satin cloth selected for the investigation is 70% mercerized cotton and 30% polyester. The areal density of the satin fabric range between 230-254 gsm with at least 100 yarns per inch in the warp direction and at least 85 yarns per inch in the fill direction. The plain weave satin is preferred because it is a weave that already possesses good strength and can be reinforced to give a light weight highly serviceable fabric.

Polyester used in the satin is a synthesized polymer, it tends to be very resilient, quick drying, resistant to biological damage and able to hold forms well. While polyester is often maligned as a textile, it has many useful applications hence polyester is not just a textile. It is made from polyethylene terephthalate (PET), the same material used to make plastic drink bottles. Polyester is a plastic, invented in Britain in the early 1940s and it has become popular for its easy care, drape and versatility. To make polyester fiber, an extruder is used to produce very fine threads of PET. Polyester clothing tends to be slippery and silky to feel, the polyester fibers used to make clothing can be knitted or woven, although most are knit, to maximize the flexibility of polyester. The important properties of the satin fabric selected towards the second reinforcement material are presented in Table 4.4.

<table>
<thead>
<tr>
<th>Density, Kg/m²</th>
<th>Tensile Strength, MPa</th>
<th>Tensile Modulus, GPa</th>
<th>Elongation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>920-1050</td>
<td>750-900</td>
<td>30-35</td>
<td>2.2-3.8</td>
</tr>
</tbody>
</table>

4.3 SPECIMEN PREPARATION

Hand layup method is used for producing reinforced plastic laminates. In this method, reinforcement fabrics are manually placed onto the mould in the required orientation. The resin is then impregnated into the ply by brushing liquid resin onto the reinforcement and then the rollers are used to thoroughly wet the reinforcement with the resin matrix material to enable good compaction and to remove entrapped air.

Reinforcement fabric both satin and glass are trimmed and tailored to suit the laminate size, 5% of excess surface area of the fabric is added to give safer margins.
Epoxy resin and the hardener were mixed properly in specified ratio. The milder sheet was then laid on a flat surface, on to which mold releasing agent is thoroughly applied, otherwise on solidification laminate adheres to the surfaces. A layer of epoxy was coated on the sheet and then composite laminate is made by building layer upon layer of glass and satin fabrics with a layer of resin in between two such fabrics to obtain the desired laminate thickness and ply orientations. While laying, care was taken to avoid air bubble and wrinkling of fabric. Finally, a milder sheet was taken and mold release agent was applied on to it, and then a layer of resin mix was applied on to the layup. The milder sheet with releasing agent was put onto the last layer of the composite. A flat board was then put on this sheet and dead loads were applied on to this prepared composite to obtain a constant pressure of approximately 200 KPa. The brushes used for resin application is with hard bristles because it will not permit air to entrap between bristles. Ample precautions were taken to minimize voids in the material and maintain homogeneity. Entire process of layup is carried at room temperature and the stacking sequence of layers is in such a way to obtain symmetric hybrid laminates. The mold is allowed to get full curing for about 48 hours, after which the prepared sample was ripped off the mold and it is at this stage that the laminate develops full mechanical properties.

After curing, coverings and releasing agents were removed from the composite. The laminate is then cleaned and edge trimming is done to get the required size. When the composite laminate is ready and resin is fully cross-linked, the laminate is inspected to detect the presence of voids and delaminations, followed by final machining to cut, trim or shape the desired part [52].

4.4 TEST CONFIGURATION

The composite laminates fabricated with symmetric layup when cured, the difference in the contractions in longitudinal and transverse directions creates significant residual stresses. The effect of these residual stresses results in saddle shape of the laminate. But this change in shape is normally due to shrinkage of laminates, there are two sources of shrinkage that lead to this residual stress. One is the natural shrinkage of the resin during the cure process, which is independent of the curing temperature. Another source is the thermal expansion due to the elevated temperature caused by the exothermal condition during the cure, which is common in epoxy resins, these residual stresses are attributed to the curing temperature of the composites [2,87,94,173]. In this research work laminate
curing was at room temperature, therefore no residual stress was expected for the composite laminates. The room temperature cured laminates on testing indicate that there was no change in shape due to residual stress.

The higher the fiber content the better is the mechanical performance of composite laminates, but if the resin percentage is less, then the laminates are more prone to damages. Smaller proportions of resin results in reduced interlaminar shear strengths, delaminations, debonding, fiber pullouts, poor surface finish, etc. According to Gremel [68] the maximum achievable and ideal ratio is about 75% of fiber content and 25% resin. Keeping these facts in view the fiber to resin proportion selected for this investigation is 60:40. Since the laminates produced in this study are hybrid laminates with two types of reinforcements, the overall percentage of fiber content will remain as 60%, but internally the percentages of glass and satin fabric are varied to suit the test configuration. In order to reach the goals of this study, the research was divided into six phases:

1. **Fabrication of Laminates:**
This includes preparation of fabric-reinforced hybrid composite laminates with three different volume fractions of the constituent materials; epoxy resin, E-glass fabric, and textile satin fabric. The volume fraction of the epoxy matrix being 40% for all the samples, while the volume fraction of glass fabric was 15, 30 and 45% and the corresponding volume of satin fabric was taken as 45, 30 and 15%. For every combination of the candidate material, two fiber orientations were selected; $0^\circ/90^\circ$ and $\pm 45^\circ$ orientations. For all the specimen configurations, the dimensions are in accordance with ASTM standards.

2. **Mechanical Testing of the Laminates:**
Experimental investigations to characterize the mechanical behaviour of composite laminates were intended to measure the global response of the sample by a series of tests. Axial tension, compression, impact, flexure and open hole laminates under tensile and compressive loads were chosen to characterize the material. Open hole tension (OHT) and open hole Compression (OHC) laminates have centrally drilled holes with five different diameters; $\Phi 2$ to $\Phi 10$ mm in steps of 2mm.
3. **Damage Characterization:**

Drop weight impactor was used to induce damage on the composite laminates. The hybrid composite laminates were subjected to low velocity impacts at different impact energies. Two impactor masses and five different impactor heights were considered, i.e. impactor heights range between 0.5m to 2.5m in steps of 0.5m. To analyze the effect of multiple impacts on the laminate, an impact height of 0.5m was used to generate impact energies for the selected impactor size. Compression after impact (CAI) tests was conducted on composite laminates to evaluate the damage tolerance of the material.

4. **Strength Degradation:**

In order to analyze the effect of environment on the strength degradation, five different types of environments have been selected in the present investigation; aqueous, saline, freezing, acidic and organic. Composite laminates exposed to these environments at different durations ranging from 50 to 250 hrs were subjected to impact tests to analyze the strength degradation.

5. **Drilling of Laminates:**

Drilling of holes on composite laminates was carried out by selecting high-speed steel (HSS) drills. Eight kinds of drills were used with different shapes, sizes and point angles. The drilling performance was investigated by considering three different drill diameters (viz. 4mm, 6mm and 8mm), three point angles (viz. 60°, 80° and 100°) and two step drills with 4mm and 6mm steps on 8mm drill. Investigations were extended even to analyse the influence of specimen thickness by selecting two different thicknesses. For all the above drilling operations, five different drill speeds were used, viz. 105, 350, 550, 951, and 1625rpm.

6. **Modeling of laminates:**

For the purpose of validation of the experimental results, ANOVA technique along with regression analysis was used. Percentage contribution of individual parameter on the variables is estimated, the regression equation are used to determine the deviation of regression values with the experimental results. In addition analysis software (Ansys) was used to validate the experimental results in some selected cases.
4.5 EXPERIMENTAL PROCEDURE

All the experiments incorporated in this research were carried at macroscopic level for the specimens consisting of glass and satin fabric embedded in an epoxy matrix. There are several advantages of using macroscopic specimens as model specimens. First, a large specimen size reduces the scatter inherent in microscopic specimens. Second, in contrast to microscopic specimens, one has control over the shape of the macroscopic matrix. Micro-droplets naturally assume an elliptical shape. The diameter of the droplet and hence the effective volume fraction of the fiber within the droplet changes as the droplet length changes. Experimental observations show that fiber volume fraction decreases at longer droplet lengths. Third, the debond growth along the interface in some specimens is quite common. Therefore the macroscopic specimens provide more information than possible from most microscopic specimens [36,107,164,179].

The hybrid composite laminates on curing were cut into strips of various dimensions to suit the specimen standards as per ASTM and then sanded by using silicon carbide sand paper for the purpose of removing edge burrs on the cut surfaces. The test ready specimens were finally tested for their thickness, atleast five randomly selected points were measured and the results were averaged [43,106,179]. The specimen dimensions for various mechanical tests as per ASTM standards are indicated in the Table 4.5. The composite laminates which is also sometimes called as test coupons were fabricated with three different volume fraction combinations in such away that ±0.5% variation in volume fraction is expected and all the experimentation was carried out at room temperature. The specifications of the testing equipment, test method, test significance and specimen details are discussed at later stages in the respective chapters.

4.6 SPECIMEN STANDARDS

American Society for Testing and Materials (ASTM) provides the standards for characterization and performance of materials. The properties of materials vary with specimen preparation, specimen dimensions and with speed and environment of testing. Hence, when materials characterization is desired, the greatest care must be exercised to ensure that all samples are prepared and tested exactly the same way. In this research
work a series of experimentation is a requirement, therefore 3-5 samples were tested in each category and the various test methods and specimen standards used in this study are illustrated in Table 4.5.

**Table 4.5 Standard test methods and specimen standards used in this research [7].**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Test Type</th>
<th>ASTM Standard</th>
<th>Laminate Dimensions, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Impact Resistance of Composites</td>
<td>D256</td>
<td>12.7±0.1 60±1 3.17 to 12.7</td>
</tr>
<tr>
<td>2.</td>
<td>Moisture Absorption of Composites</td>
<td>D570</td>
<td>-- -- --</td>
</tr>
<tr>
<td>3.</td>
<td>Rockwell Hardness of composites</td>
<td>D785</td>
<td>-- -- --</td>
</tr>
<tr>
<td>4.</td>
<td>Flexural Properties of Composites</td>
<td>D790</td>
<td>13±0.1 130±2 6.4 to 10</td>
</tr>
<tr>
<td>5.</td>
<td>Specific Gravity and Density of Plastics</td>
<td>D792</td>
<td>-- -- --</td>
</tr>
<tr>
<td>6.</td>
<td>Defects In Reinforced Plastics</td>
<td>D2562</td>
<td>-- -- --</td>
</tr>
<tr>
<td>7.</td>
<td>Void Content of Reinforced Plastics.</td>
<td>D2734</td>
<td>-- -- --</td>
</tr>
<tr>
<td>8.</td>
<td>Impact Resistance of laminates for Falling Weight</td>
<td>D3029</td>
<td>100 100 5.2</td>
</tr>
<tr>
<td>9.</td>
<td>Tensile Properties of Oriented Fiber Composites</td>
<td>D3039</td>
<td>25.4±0.1 127±2 3.25 to 4.0</td>
</tr>
<tr>
<td>10.</td>
<td>Fiber Content of Reinforced Resin Composites</td>
<td>D3171</td>
<td>-- -- --</td>
</tr>
<tr>
<td>11.</td>
<td>Compressive Properties of Composites</td>
<td>D3410</td>
<td>38.1±0.1 60±0.2 6.4 to 8.0</td>
</tr>
<tr>
<td>12.</td>
<td>In Plane Shear Response of Composites</td>
<td>D3518</td>
<td>25.4±0.1 127±2 3.25</td>
</tr>
<tr>
<td>13.</td>
<td>Open Hole Compression Strength of Composites</td>
<td>D6484</td>
<td>38.1±0.1 60±0.2 6.4 to 8.0</td>
</tr>
</tbody>
</table>

With W/d=6