1. INTRODUCTION

1.1. COMPOSITE MATERIALS

Composite materials are engineered or naturally occurred materials prepared from two or more ingredient materials with appreciably different physical and chemical properties that remain detach and distinct within the refined structure. Most of the composites have sturdy and stiff fibers in a matrix which is weaker and less stiff. The purpose is usually to make a component that is physically strong and stiff, with low density. Industrial material commonly has glass or carbon fibers in matrices based on thermo-setting polymers, like epoxy or polyester resins. Sometimes, thermoplastic polymers are preferred, as they are mouldable after initial production. (Martin A.M., 2013)

The majority of the composites can be customized to obtain characteristics better than individual constituents. A composite made from polymer reinforced with fiber is called FRP (Fiber Reinforced Polymer) composite. "Considering a composite, that involves two or more macro constituent phases, the matrix is referred to as a continuous phase and the fibers are called reinforcing phases" (Mirmira, 1999). The fibers boost the strength and stiffness, increase thermal related and fatigue properties, offer better dimensional firmness and electrical resistivity, while the main function of the resin is to transmit load, to hold the fibers, protect fibers from the environment and mechanical weariness. Matrix also carries transverse loads and inter laminar shear stresses (Barbero, 1998). The advantages of composites consist of high strength to weight ratio, non-corrosiveness, low maintenance, high electrical and wear resistance, electromagnetic transparency etc. Composites can be manufactured in many ways depending upon matrix, reinforcement, and purpose like hand-lay-up, compression moulding, resin transfer moulding (RTM), VARTM, pultrusion, filament moulding, and autoclave etc.

1.2 Applications of Composite Materials

Fiber Reinforced Polymer Composites are used for manufacturing in the following area,

- **Aerospace and related structures**: The army aircraft industry has mainly led to the use of polymer composites. In commercial air-lines, the use of composites is steadily increasing. The space shuttle and satellite systems use graphite/epoxy for many structural parts

- **Marine related**: Bodies of boats, canoes, kayaks, etc.
- **Automotive**: Components like body panels, leaf springs, driveshaft, bumpers, doors, racing car bodies, etc.
- **Sports goods**: Golf clubs, skis, tennis rackets, fishing rods etc.
- Bullet- proof vests and other armoured parts.
- Tanks for chemical storage, pressure vessels, piping, pump body, valves, etc.
- **Biomedical and its applications**: Medical implants, orthopaedic devices, X-ray tables.
- Bridges made of polymer composite materials are getting hold of wide acceptance due to their low weight, corrosion resistivity, long life cycle, and limited earthquake damage.
- **Electrical related:** Panels and housing, switchgear, insulators, and connectors and many more promising applications. (**Jose et al.** 2012)

1.3 Characteristics and Classification of the Composite Materials

Composites are heterogeneous materials. The properties of a composite differ significantly from point to point in the material, depending on which material phase the point is positioned in. several artificial composites, particularly those reinforced with fibers, are “anisotropic”, which means their properties differ with direction (the properties of “isotropic” materials are the same in every direction).

Composite materials are classified according to their content, i.e. base material and filler material. The base material, which binds or holds the filler material in structures, is termed as a matrix or a binder material, while filler material is present in the form of sheets, fragments, particles, fibers, or whiskers of natural or synthetic material. As represented in Fig. 1.1 composites are categorized into three main classes based on their structure. (**Uzay,** 2017)

1.4 Fiber Reinforced Polymer Composites

Fiber Reinforced Polymer-matrix (FRP) composites consist of a polymer resin as the matrix, with fibers as the reinforcement medium. These materials are used in the variety of

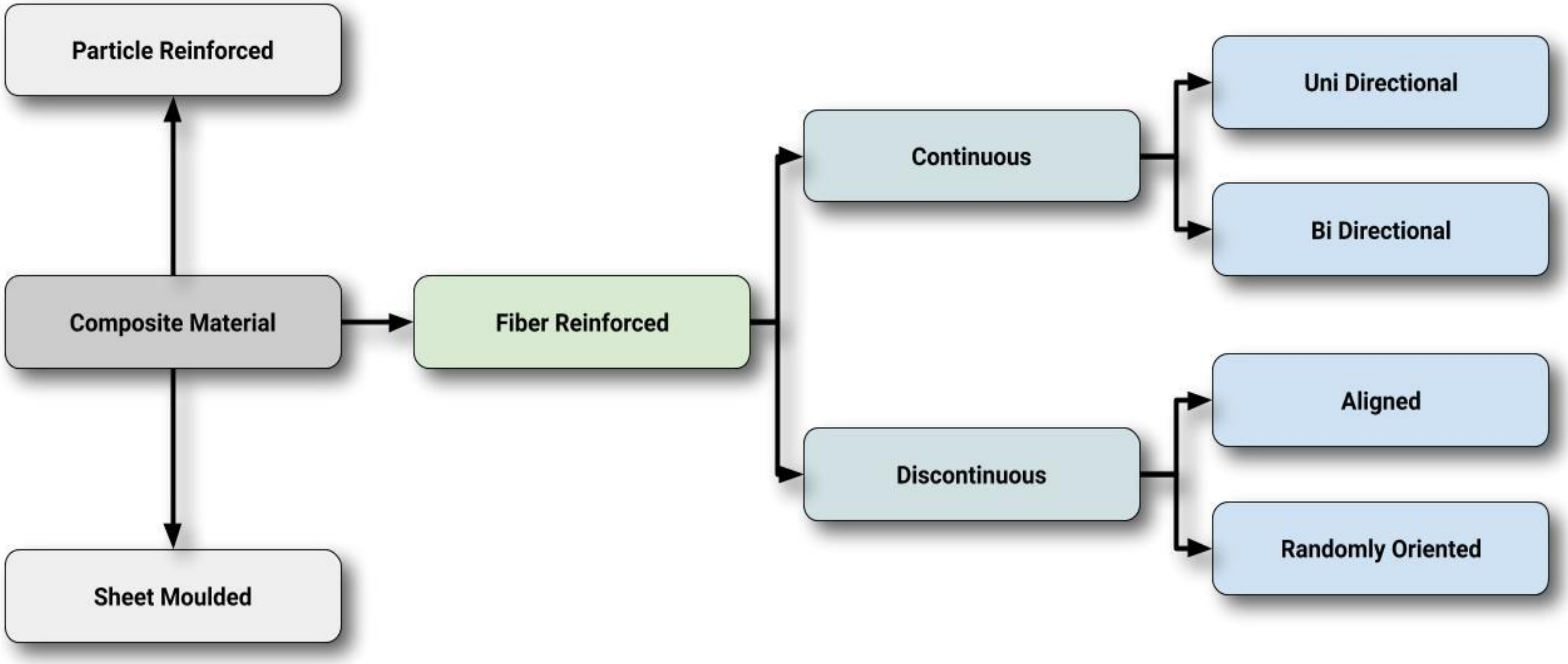

Figure 1.1 Classification of Composites

applications, as well as in the major quantities, in light of their room-temperature properties, ease of manufacture, and cost. The performance of a fiber-reinforced composite is decided by fibers' length, shape, orientation, and composition of the fibers and the mechanical properties of the polymer matrix. In this section fibers and polymer, resins are discussed according to reinforcement type (i.e. Synthetic and Natural), along with their use and the various polymer resins that are applied.

1.4.1 Synthetic Fibers

Artificial fibers that are produced by chemical synthesis are called synthetic fibers (SFs) and further categorized as organic or inorganic based on their content. (**Kim et al.** 2004). Generally, the potency and stiffness of fiber materials are much better than that of the matrix material, making them a load-bearing component in the composite structure. (**Nielsen L.E and Landel R.F.**1994).

1.4.2 Natural Fibers

Natural fibers (NFs) are very easy to get, widely available in nature. They disclose some exceptional material properties like biodegradability, low cost per unit volume, high strength, and specific stiffness. Composites made of NF reinforcements seem to carry some miscellaneous properties over synthetic fibers, like reduced weight, cost, toxicity, environmental pollution, and recyclability. Different categories of natural and synthetic fibers are shown in the fig. no.1.2

Table 1.1 Properties of Reinforced Material **(McAlvin,** 2015)

Types of Fibers	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation at the Break (%)
Jute	400-800 Mpa	10–30 GPa	5.5-12.6
Basalt	3000–4000 MPa	93–110 GPa	3.1–6
Carbon	3500–6000 MPa	230–600 GPa	1.5–2.0

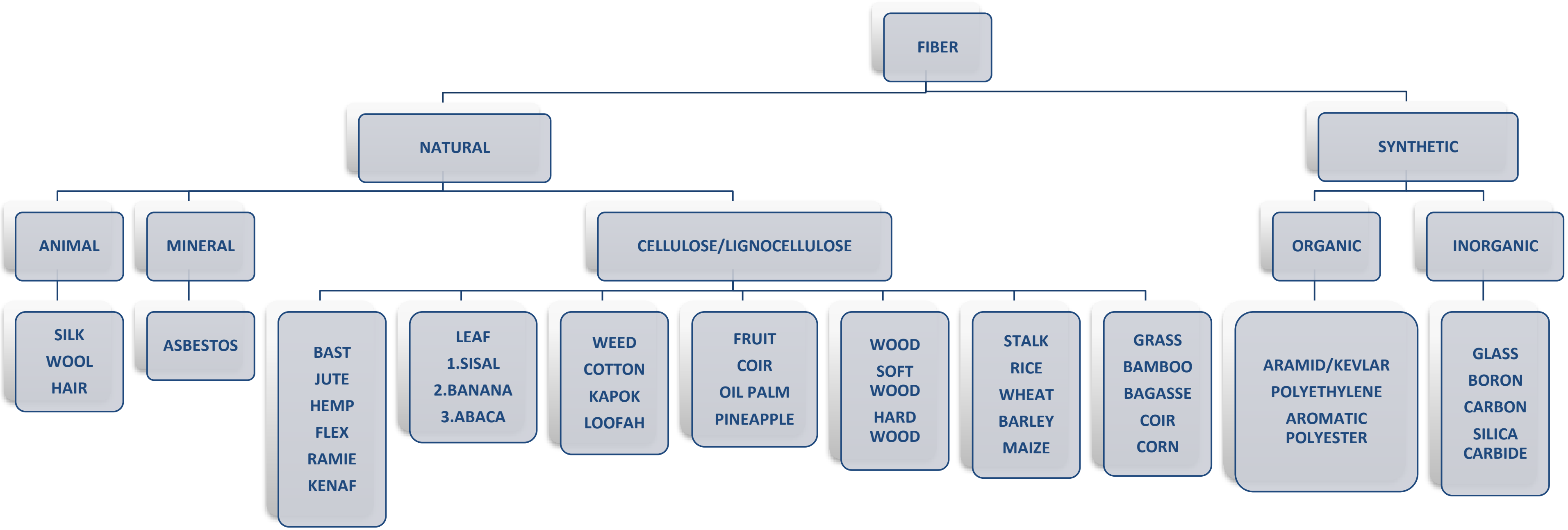

Figure No.1.2 Classification of Fibers

1.4.3 Polymers-Resins

The main functions of the resin are to transmit stress between the reinforcing fibers, act as a glue to grip the fibers together, and defend the fibers from mechanical and environmental damage. Resins are separated into two major groups known as thermoset and thermoplastic. Thermoplastic resins become soft when heated, and maybe shaped or moulded while in a heated semi-fluid condition and become rigid when cooled. (Composite Basics: **www.mdacomposites.org**).

They have high heat stability, chemical resistivity, good dimensional stability, and also high creep properties due to its three-dimensional cross-linked composition. The most familiar thermosetting resins for composite manufacturing are unsaturated polyesters, epoxies, vinyl esters and phenolic.

1.4.3.1 Polyester

A range of raw materials and processing technology are existing to get the desired properties in the formulated or processed polyester resin. Polyesters are adaptable because of their capacity to be customized or tailored during the building of the polymer chains. They have been found to have unlimited usefulness in all different composites industry. The main advantage of these resins is a balance of properties (i.e. mechanical, chemical, electrical) dimensional stability, cost, and ease of managing for processing. **(**Composite Basics: **www.mdacomposites.org**)

1.4.3.2 Epoxy

Epoxy resins have well-established evidence in a wide variety of composite parts, structures, and concrete repair. The structure of the resin can be engineered to yield different products with varying performance. A major advantage of epoxy resins over unsaturated polyester resins is their lesser shrinkage. Epoxy resins have specifically good UV resistance. However, epoxies discharge little odour as compared to polyesters. **(**Composite Basics: **www. mdacomposites.org**)

1.4.3.3 Vinyl ester

Vinyl esters were developed to mix the advantages of epoxy resins with the better handling/faster cure, which are distinctive for unsaturated polyester resins. These resins are developed by reacting epoxy resin with acrylic or methacrylic acid. Vinyl esters offer mechanical toughness and excellent corrosion resistance. Thermal resistant properties of these resins are good as they are tested for retention of mechanical properties at elevated temperature as well for also have good corrosion resistance in a range of chemical environments (**McAlvin,** 2015)

1.4.3.4 Phenolic

Phenolic is a group of resins usually based on phenol (carbolic acid) and formaldehyde. Phenolic are thermosetting resins that cure by a condensation reaction producing water that should be separated during process. Phenolic composites have a lot of attractive performance qualities like high-temperature resistance, excellent thermal insulation, creep resistance and sound damping properties and corrosion resistance **(**Composite Basics: **www. mdacomposites .org**)

1.4.3.5 Polyurethane

Polyurethanes as an elastomeric have better toughness and abrasion in such applications as solid tires, wheels, bumper components, or insulation. Polyurethanes are sometimes used to bond composite structures together. Advantages of polyurethane adhesive bonds are that they have better impact resistance, the resin cures speedily and the resin bonds well ona variety of different surfaces such as concrete. **(**Composite Basics: **www.mdacomposites.org**)

1.5 Selection of Resin

Unsaturated polyester is inexpensive and it is used due to its outstanding processability and good cross-linking propensity as well as mechanical properties when cured and because of these reasons, unsaturated polyester has been selected as a matrix to examine the effect of conductive filler in jute fiber reinforced polymer composites.

Vinyl ester resins bond in a parallel way to Polyester resins with cross-linking of side groups along a backbone. Vinyl ester resins are less permeable of water due to the more firmly bonded structure of the side groups. This cross-linking of side chains is the cause that vinyl ester resins have exceptional thermal stability. Hence vinyl ester is used as a matrix to study post-process curing and in-process curing at a different set of pressure and temperature and their effects on the mechanical strength of the polymer composite.

Table 1.2 Mechanical Properties of Polyester and Vinyl Ester (**Jose**, 2012)

Polymer	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (GPa)
Polyester	34-105	2.1-3.5	70-110	2-4
Vinyl ester	73-81	3-3.5	130-140	3

1.6 Mechanical and Thermal Behaviour of Fiber Reinforced Composites

Composites are heterogeneous material. Therefore, the real performance of composite materials is quite dissimilar from the predictions coming from the conventional material. Because of the increasing structural performance required for inventive composites, the knowledge of the mechanical properties for different loading cases is a basic source of concern. Experimental categorization in different environmental conditions is extremely important to understand the mechanical behaviour of these new materials.

The performance of composite materials is often responsive to changes in temperature. This arises for two main reasons. Firstly, the reaction of the matrix to an applied load is temperature-dependent and, secondly, changes in temperature can affect internal stresses developed due to differential thermal contraction and expansion of the two constituents. In addition, significant stresses are usually present in the material at ambient temperatures, while it has been cooled at the end of the fabrication process. Changes in internal stress state on varying the temperature can be considerable and may strongly affect the response of the material to an applied load. Finally, the thermal conductivity of composite materials is of concern, since many applications and processing engage heat flow of some type. This property can be broadcasted from the conductivities of the constituents, although the situation may be difficult by poor thermal contact across the interfaces.

The purpose of the present research work is to characterize a composite material developed for such applications considering the effect of load, temperature, and time during the development of composites. Test specimens were prepared from jute, basalt, and carbon fibers using vinyl ester as a matrix at different combinations of temperature, load (pressure) and time derived using the Taguchi method by applying in-process and post-process curing. Mechanical tests were conducted and the effects of temperature, load, and time on mechanical properties (tensile strength and flexural strength) were observed. Test specimens from jute using polyester as matrix were also prepared with different fillers (Cu, Al, and SiC) to observe their effects on thermal conductivity, and also mechanical strength was compared to know the effects of fillers.