5.1 INTRODUCTION

Composites are those materials formed by aligning extremely strong and stiff continuous or chopped fibers in a polymer resin matrix or binder. The fibers make them useful; the fibers are typically 50 times stronger and 20-25 times stiffer than the matrix polymers. The role of matrix is primarily that of a glue or binder which enables the fibers to support the applied load. Fibers are combined with a resin and laminated to support the applied load. Many laminates exhibit mechanical properties equal to or exceeding those of most metals [1].

Combining and orienting materials to achieve superior properties is an old and well-proven concept; examples of this synergism around in nature [2]. Wood contains an oriented hard phase which provides strength and stiffness and a softer phase for toughness. Other natural composites are found in teeth, bones, bird feathers and plant leaves. The use of chopped straw by the Israelites to control residual cracking in bricks is one example [3]. More representative of modern structural composites are Mongolian bows, which are laminates of wood, animal tendons and silk [3]. Japanese samurai swords are formed by repeated folding of a steel bar back upon itself. The resulting structure contains as many as $2^{15}$ alternating layers of hard oxide and tough, ductile steel.

Fiber Reinforced Polymer (FRP) composites is defined as a polymer matrix, either thermoset or thermoplastic that is reinforced with a fiber or other reinforcing material with a sufficient aspect ratio (length to thickness) to provide a discernible reinforcing function in one or more directions. FRP composites are different from traditional construction materials such as steel or aluminium. FRP composites are anisotropic (properties only apparent in the direction of the applied load) whereas steel or aluminium is isotropic (uniform properties in all directions, independent of applied load).
Therefore, FRP composite properties are directional, meaning that the best mechanical properties are in the direction of the fiber placement [4-5].

FRP composites can be of different types and made up of jute [6-7], sisal [8], coir [9], banana cotton [10], straw [11], pineapple leaf [12], cotton-kapok [13], graphite [14-20], aromatic polyamides [21-22], glass [23-25] and carbon [26] as a reinforcements.

Many terms have been used to define FRP composites. Modifiers have been used to identify a specific fiber such as Glass Fiber Reinforced Polymer (GFRP), Carbon Fiber Reinforced Polymer (CFRP) and Aramid Fiber Reinforced Polymer (AFRP). Another familiar term used is Fiber Reinforced Plastics. In addition, other acronyms were developed over the years and its use depended on geographical location or market use. For example, Fiber Reinforced Composites (FRC), Glass Reinforced Plastics (GRP) and Polymer Matrix Composites (PMC) can be found in many references. Although different, each of aforementioned terms mean the same thing; FRP composites [4-5].

A composite is a heterogeneous substance consisting of two or more materials which does not lose the characteristics of each component. This combination of materials brings about new desirable properties. Naturally occurring composites include tendon, bone, bamboo, rock and many other biological and geological materials. For composite engineering applications, we restrict ourselves to synthetic polymer matrices which are used with naturally occurring mineral fillers such as wollastonite, silica, mica and calcium carbonate and synthetic fibers like glass fibers and carbon fibers.

The main advantages of polymer composites lies in excellent specific mechanical properties, corrosion resistance, parts integration possibilities; potentially lower cost and light
weight. The predominant disadvantages are designers lack of experience, knowledge and material data bases, as well as in low temperature tolerance, arduous manufacturing and quite often the higher cost. However, the potential advantages of composites in engineering applications are alluring, the complexity they introduce in design and manufacturing demands a lot from both designers’ and manufacturers’ points of views.

Polymer composites are found in all engineering fields where they compete with more traditional construction materials, such as wood, steel, aluminium, carbon, glass and boron [27-39]. Automobile, boat, aircraft, construction and electrical usages are among the most important applications areas.

Fiber reinforced composite materials using synthetic resins have attained significant development in the last few decades because of their desirable properties such as light weight, high strength-to-weight ratios and comparatively easy processability. Most commercially important composites are based on glass fibers as reinforced material. Other fibers which have been successfully utilized for composite preparation include carbon fiber, boron fiber, asbestos fiber etc though their applications are not as wide spread as glass-fiber-reinforced composites.

Attempts have also been made to prepare composites based on natural fibers or fillers including jute fiber, wood flour, banana fiber etc. Their use is very limited till today and mainly confined to those areas where mechanical strength requirement is not very high but natural fibers are relatively inexpensive and these renewable resources which are abundantly available and under utilized have the potential to be used as fillers and reinforcements in polymers. Natural fibers are themselves cellulose reinforced materials [40].
The development of reinforced plastics has traditionally involved the addition of a particular fibers or fillers [41]. These fibers and fillers usually tend to increase the stiffness of composite materials. The extent of the reinforcement depends upon many factors, such as shape and amount of filler, the interfacial adhesion between the filler and the polymer matrix, the distribution of fiber in the matrix, the surface treatment of fiber and the properties of fiber or filler [42].

The recent years there is an increasing interest in natural fibers as a substitute for glass fibers mainly because of their low specific gravity, low cost, as well as their renewable and biodegradable nature [43].

Among all the natural fibre reinforcing materials, jute appears to be a promising material because it is relatively inexpensive and commercially available in the required form. However, its mechanical and physical properties are highly inconsistent and depend on geographic origin, climatic growth conditions and processing techniques [44]. Jute is one of the most important natural vegetal fibres, and is produced in India, Bangladesh, Thailand, Vietnam and other countries. It contains 56–64% cellulose, 29–25% hemicelluloses, 11–14% lignin and a small proportion of fats, pectin, ash and waxes [45]. Munikenche Gowda et al. [44] studied some mechanical properties of unsaturated jute reinforced polyester composites. Saha et al. [46] studied of jute fibre reinforced polyester composites by Dynamic Mechanical Analysis.

Lignocellulosic fibres like sisal, jute, coir, pineapple and banana have been used as reinforcements in thermoset matrices. Among these fibres, jute is of particular interest in that its composites have high impact strength in addition to having moderate tensile and flexural properties compared to other lignocellulosic fibres [47].
Several studies have been reported on jute-reinforced polymer composites, especially with epoxy, phenolic, and polyester matrices [48-51]. Roe and Ansell [48] have studied the mechanical properties of jute reinforced polyester composites containing uniaxially oriented jute fibres. Bhattacharya et al. [49] have made composites with jute fibres in a phenolic resin. Sridhar et al. [50] have studied the tensile, flexural and impact properties of unidirectional and bidirectional jute/glass hybrid polyester composites. Varma et al. [51] have studied the mechanical properties of hybrid composites of glass and modified jute fabric in unsaturated polyester resin. An improvement in the mechanical properties of laminates was observed when jute fabric was modified by titanate treatment.

There is a growing interest in the use of agro-fibres as reinforcing components for thermoplastics, because they are renewable, biodegradable and environmentally friendly. Again, the growing environmental concern has made plastics a target of criticism due to their lack of degradability. So there has been a lot of interest in research committed to the design of biodegradable plastics [52]. Biodegradable polymers are considered as an environmental waste-management option [53]. They constitute a loosely defined family of polymers that are designed to degrade through action of living organisms and they offer a possible alternative to traditional non-biodegradable polymers where recycling is unpractical or not economical. The management of solid waste disposal with regard to the decreasing availability of landfills, the litter problem and the pollution of marine environment are becoming very urgent in the industrial countries and risk to extend very quickly to the developing countries. Interest in biodegradable plastics is being revived by new technologies developed by major players, such as Bayer, DuPont and Dow Cargill [54]. Demands for biodegradables are forecast to grow.
nearly 16% per annum [55]. The manufacture, use and removal of traditional composites, usually made of glass, carbon or aramid fibres reinforced thermoplastics and thermosetting resins are considered critically because of environmental problems. Natural fibre reinforced biodegradable matrix composites (biocomposites) will get much attention in the future [56]. Jute, the so-called golden fibre from eastern India and Bangladesh is one of the most common agro-fibres having high tensile modulus and low elongation at break. If the low density (1.4 g/cm$^3$) of this fibre is taken into consideration, then its specific stiffness and strength are comparable to the respective quantities of glass fibres [57].

Unidirectionally reinforced fiber composites are manufactured by continuous thermal hardening of heat curable unsaturated polyester resin used for impregnating of fiber strands by means of IR heating [58]. Light weight thermoset FRP- thermoplastic composites were manufactured by insert molding from unsaturated polyester resin and glass cloth [59].

The composites from unsaturated polyester resin and nano TiO$_2$ was synthesized by the “reaction method” during which the nano TiO$_2$ powder tend to hydrolytically react forming hydroxyl which reacts with the carbonyl group in the UPR and thus improving the strength and flexibility of the resin [60].

V. N. Studentsov and co-workers have prepared reinforced polymer composites based on unsaturated polyester resin PN-15[61]. Carbon fiber composites were prepared from a set of unsaturated polyester resins with different ratios of maleic anhydride, o-phthalic anhydride and 1, 2-propylene glycol to improve interfacial strength [62]. Glass fiber reinforced laminated composites from a brittle unsaturated polyester resin were prepared and study under influence of
matrix ductility and fiber architecture on the repeated impact response [63]. The composite moldings are prepared from unsaturated polyester resin and glass fiber and laminating with resin mortars by Y. Mukoto et al. [64].

Composites based on surface modified kaolinite and unsaturated polyester resin for mechanical properties and electrical properties were prepared by B. Jaljakumari et al. [65]. A coloured glass fiber reinforced composites having improved shrinkage resistance and colour homogeneity were prepared by molding a mixture of maleic anhydride, phthalic anhydride, propylene glycol copolymer -styrene solution, electron beam cross linked polyethylene, ter -Bu-perbenzoate, kaoline, talc, quinacridonered MgO and glass fibers[66].

An over view of building materials from local resources is briefly presented with a particular attention on natural fibers based composites. The performance of polymer composites made from this natural fibers and unsaturated polyester resin was evaluated under various humidity, hygrothermal and weathering conditions [67]. The influence of commercially available dispersants on the rheological behaviour of an unsaturated polyester alumina composite was systematically investigated. In addition, the effect of a chemical surface hydro-phobisation using a silanisation agent was determined [68]. Polyester polyol/titania hybrid resins and their corresponding polyurethane/titania hybrid films were prepared by in situ method via sol–gel process of titanium n-butoxide under acidic condition. The effects of the contents and types of titania sol on the microstructure and some mechanical and optical properties of the hybrids were investigated [69].

New injection-molding technology has been developed using unsaturated polyester (UP) resin in order to produce bonded Sm–Fe –N anisotropic magnets. Sheet magnets of 50 mm × 20 mm × 0.36 mm are successfully made within a cycle
time of 90 s. Magnetic properties obtained are almost the same as those obtained in column magnets of 10 mm × 7 mm [70].

The thermal degradation and fire resistance of different natural fibre composites were studied. Unsaturated polyester (UP) and modified acrylic resins (Modar) were used as matrix composites. The smoke emission of the materials was also analysed, as well as, the performance against the fire of the biocomposites and glass reinforced composites was compared [71].

A series of silica particles with different size and surface groups were prepared through the sol–gel process of tetraethyl or thosilicate, then directly introduced into polyester polyol resins via in situ (IS) polymerization or blending (BL) method and investigated by Fourier transform infrared spectroscopy (FTIR), thermal gravimetric analysis (TGA), viscosity measurement, particle size analyzer and transmittance electron microscope (TEM), respectively [72].

Composites based on pure gypsum and polyester–styrene resins have been prepared using various doses of gamma radiation. Some physical properties of the prepared composites and the influence of irradiation dose on it have been studied as: compression strength, hardness, thermal decomposition temperature in nitrogen or oxygen, and the change in weight in aqueous solutions with different pH values [73].

There are many reports about the use of jute as reinforcing fibres for thermosets and thermoplastics [74]

5.2 BENEFITS OF COMPOSITE MATERIALS [75]

FRP composites have many benefits to their selection and use. The selection of the materials depends on the performance and intended use of the product. The composites designer can tailor the performance of the end product with
proper selection of material. It is important for the end user to understand the application environment, load performance and durability requirements of the product and convey this information to the composites industry professional. A summary of composite material benefits include:

- Light weight
- High strength-to-weight ratio
- Directional strength
- Corrosion resistance
- Weather resistance
- Dimensional stability
- Low thermal conductivity
- Low coefficient of thermal expansion
- Radar transparency
- Non-magnetic
- High impact strength
- High dielectric strength (insulator)
- Low maintenance
- Long term durability
- Part consolidation
- Small to large part geometry possible
- Tailored surface finish

5.3 ADVANTAGES OF COMPOSITE MATERIALS [76]

Composites have many engineering advantages over synthetic polymers and copolymers. Some of these advantages are:

- Reinforcement of the resin resulting in increased tensile strength, flexural strength, compression strength, impact strength, rigidity and combination of these properties.
- Increased size stability.
- Improved fire retardancy.
- Corrosion protection.
• Improved electrical properties; reduction of dielectric constant.
• Coloring.
• Improved processability; controlled viscosities, good mixing, controlled orientation of fibers.

One of the most important properties composite materials offer is the strength per density or modulus per density termed as specific strength and specific modulus respectively. For transportation applications including aerospace applications, the weight of the vehicle is a critical importance for energy saving and payload increase. Those materials used for polymer matrix composites have usually much less density than metallic materials, thus specific properties often far exceeds that of metallic parts.

5.4 COMPOSITION
Composites are composed of resins, reinforcements, fillers, additives, catalyst, promoters and inhibitors. Each of these constituent materials or ingredients plays an important role in the processing and final performance of the end product. The resin or polymer is the "glue" that holds the composite together and influences the physical properties of the end product. The reinforcement provides the mechanical strength. The fillers and additives are used as process or performance aids to impart special properties to the end product.

The mechanical properties and composition of FRP composites can be tailored for their intended use. The type and quantity of materials selected in addition to the manufacturing process to fabricate the product, will affect the mechanical properties and performance. Important considerations for the design of composite products include:
• Type of fiber reinforcement
• Percentage of fiber or fiber volume
• Orientation of fiber (0°, 45° or 90°)
• Type of resin
• Cost of product
• Volume of production (to help determine the best manufacturing method)
• Manufacturing process
• Service conditions

5.4.1 Reinforcement Materials

Bulk polymers typically have low room temperature strengths, which are as low as compared with steel or aluminium alloys and their low moduli, would result in unacceptably large deformations in structures of any size. The first principle of reinforced composites is that the reinforcement materials must support all main load sand limit deformations acceptably. The reinforcement therefore may be in the form of fibers, fabrics, particles or whiskers.

There are so many fibrous reinforcements available for preparing composite materials like glass fiber, carbon fiber, wood flour, jute fiber, cotton, paper, boron fiber, aluminium, asbestos, graphite or carbon fiber, Kevlar fiber, aramide fiber etc. inform of discrete fibers, fiber strands or woven or nonwoven fabrics [21-22, 27-39].

Woven fabrics are among the earliest based used for laminating. They provide a stronger and more impact-resistant product than nonwoven fabrics and paper [77]. In woven fabrics, the fibrous structure is stronger be cause the individual fibers are longer by virtue of spinning into yarn. The weaving pattern of the fabric controls the physical nature of the laminate. A very common weave is a square pattern in which each warp yarn passes above and below each alternate fill yarn during weaving. This gives a structure with maximum crimp. In drills and twills, each yarn still has considerable crimp as it passes from one side of the fabric to the other.
Such weaves exhibit uniform properties in the crosswise and lengthwise directions but are relatively weak owing to the great crimp in each yarn. They normally punch well and machine readily. For tougher, stronger laminates, a satin weave is often used. In an eight shaft satin, each yarn passes over seven others before passing to other side of the fabric. This greatly reduces crimp and gives long sections of parallel oriented fibers with high impact and tensile strengths. Such constructions are avoided where punchability is desired.

The best construction is the unidirectional fabric in which all warp yarns are heavy, low twist and parallel assemblies. The fill yarn is very light and crimps itself to conform to the warp yarns. Nearly all the strength is in one direction; the product resembles wood in these characteristics but dense and much stronger.

Fabrics provide better impact and tensile strength but are more expensive than paper. Their machining quality is also not good. Very finely woven fabrics are reasonably homogeneous and have better impact strength than paper but are usually very costly. Coarse fabrics are stronger and cheaper, but less homogeneous and perhaps nonpunchable products. Because of their higher cost, fabrics are seldom used in decorative laminates.

The primary function of fibers or reinforcements is to carry load along the length of the fiber to provide strength and stiffness in one direction. Reinforcements can be oriented to provide tailored properties in the direction of the loads imparted on the end product. Reinforcements can be both natural and man-made. Many materials are capable of reinforcing polymers. Some materials, such as the cellulose in wood, are naturally occurring products. Most commercial reinforcements, however, are man-made. Of these, by far the largest volume reinforcement measured either in quantity consumed or in product sales, is glass fiber. Other composite
reinforcing materials include carbon, aramid, UHMW (ultra high molecular weight) polyethylene, polypropylene, polyester and nylon. Carbon fiber is sometimes referred to as graphite fiber. The distinction is not important in an introductory text but the difference has to do with the raw material and temperature at which the fiber is formed. More specialized reinforcements for high strength and high temperature use include metals and metal oxides such as those used in aircraft or aerospace applications. Types of fiber reinforcement used for composites are as follows:

5.4.1(a) Jute Fibers

The recent years there is an increasing interest in natural fibers as a substitute for glass fibers mainly because of their low specific gravity, low cost, as well as their renewable and biodegradable nature.

Among all the natural fibre reinforcing materials, jute appears to be a promising material because it is relatively inexpensive and commercially available in the required form. However, its mechanical and physical properties are highly inconsistent and depend on geographic origin, climatic growth conditions and processing techniques. Jute is one of the most important natural vegetal fibres, and is produced in India, Bangladesh, Thailand, Vietnam and other countries. It contains 56–64% cellulose, 29–25% hemicelluloses, 11–14% lignin and a small proportion of fats, pectin, ash and waxes.

5.4.1(b) Glass Fibers

Based on alumina- lime -borosilicate composition, “E” glass produced fibers are considered the predominant reinforcement for polymer matrix composites due to their high electrical insulating properties, low susceptibility to moisture and high mechanical properties. Other commercial compositions include “S” glass, with higher strength, heat
resistance and modulus, as well as some specialized glass reinforcements with improved chemical resistance, such as AR glass (alkaliresistant).

Glass fibers used for reinforcing composites generally range in diameter from 0.00035” to 0.00090” (9 to 23 microns). Fibers are drawn at high speeds, approaching 200 miles per hour, through small holes in electrically heated bushings. These bushings form the individual filaments. The filaments are gathered into groups or bundles called “strands.” The filaments are drawn from the bushing, water and air cooled and then coated with a chemical binder or sizing to protect the filaments and enhance the composite laminate properties. The sizing also determines the processing characteristics of the glass fiber and the conditions at the fiber–matrix interface in the composite.

Glass is generally a good impact resistant fiber but weighs more than carbon or aramid. Glass fibers have excellent characteristics, equal to or better than steel in certain forms. The lower modulus requires special design treatment where stiffness is critical. Composites made from this material exhibit very good electrical and thermal insulation properties. Glass fibers are also transparent to radio frequency radiation and are used in radar antenna applications.

5.4.1(c) Carbon Fibers

Carbon fiber is prepared from polyacrylonitrile (PAN), pitch or rayon fiber precursors. PAN based fibers offer good strength and modulus values up to 85-90 Msi. They also offer excellent compression strength for structural applications up to 1000 ksi. Pitch fibers are made from petroleum or coal tar pitch. Pitch fibers have extremely high modulus values (up to 140 Msi) and favourable coefficient of thermal expansion make the material used in space/satellite applications.
Carbon fibers are more expensive than glass fibers; however carbon fibers offer an excellent combination of strength, low weight and high modulus. The tensile strength of carbon fiber is equal to glass while its modulus is about three to four times higher than glass.

Carbon fibers are supplied in a number of different forms, from continuous filament tows to chopped fibers and mats. The highest strength and modulus are obtained by using unidirectional continuous reinforcement. Twist-free tows of continuous filament carbon contain 1,000 to 75,000 individual filaments, which can be woven or knitted into woven roving and hybrid fabrics with glass fibers and aramid fibers.

Carbon fiber composites are more brittle (less strain at break) than glass or aramid. Carbon fibers can cause galvanic corrosion when used next to metals. A barrier material such as glass and resin is used to prevent this occurrence.

5.4.1(d) Aramid Fibers (Polyaramids)

Aramid fiber is an aromatic polyimide that is a man-made organic fiber for composite reinforcement. Aramid fibers offer good mechanical properties at a low density with the added advantage of toughness or damage/impact resistance. They are characterized as having reasonably high tensile strength, a medium modulus and a very low density as compared to glass and carbon. The tensile strength of aramid fibers are higher than glass fibers and the modulus is about fifty percent higher than glass. These fibers increase the impact resistance of composites and provide products with higher tensile strengths. Aramid fibers are insulators of both electricity and heat. They are resistant to organic solvents, fuels and lubricants. Aramid composites are not as good in compressive strength as glass or carbon composites. Dry
aramid fibers are tough and have been used as cables or ropes, and frequently used in ballistic applications. In present investigation jute fiber is used as reinforcement material for fabrication of composites.

5.4.2 Matrix Materials [78-79]

The purpose of the matrix material or resin in reinforced composite is mainly to hold the fibers together and to transmit the shear loads from fiber to fiber so that they resist bending and compression. It also maintains the desired fiber orientation, spacing and protect the fiber from surface damage. The role of matrix is more subtle and complex in the areas of strength and roughness. Glass, graphite and boron fibers are line are elastic, brittle solids. They fail catastrophically, without plastic flow, whenever the stress on them is sufficient to cause unstable flaw growth (surface notches).

The tendency towards brittle - fiber fracture is mitigated in several ways. The fibers are quite small and of high perfection; any flaws they contain are therefore small. Because the fibers are separated by a layer of matrix, the stress concentration and there by the tendency to transmit the crack from the broken fiber to an intact one if reduced. Thus, the combination of a brittle fiber in a brittle matrix produces a material that is quite tough, indeed much tougher than either of them alone. This synergism is achieved by a combination of mechanisms that tends to keep cracks small, isolated and blunted and that dissipates energy [3].

The primary functions of the resin are to transfer stress between the reinforcing fibers, act as a glue to hold the fibers together and protect the fibers from mechanical and environmental damage. Resins are divided into two major groups known as thermoset and thermoplastic. Thermoplastic resins become soft when heated and may be shaped or molded
while in a heated semi-fluid state and become rigid when cooled. Thermoset resins on the other hand are usually liquids or low melting point solids in their initial form. When used to produce finished goods, these thermosetting resins are “cured” by the use of a catalyst, heat or a combination of the two. Once cured, solid thermoset resins cannot be converted back to their original liquid form. Unlike thermoplastic resins, cured thermoset will not melt and flow but will soften when heated (and lose hardness) and once formed they cannot be reshaped. Heat Distortion Temperature (HDT) and the Glass Transition Temperature (Tg) is used to measure the softening of a cured resin. Both test methods (HDT and Tg) measure the approximate temperature where the cured resin will soften significantly to yield (bend or sag) under load.

In terms of commercial usages, the thermoset clearly dominates in structural composite applications. In fact, the first fiber-reinforced polymer composites was based on phenolics and unsaturated polyesters in Germany in 1940 A.D. [21].

The most common thermosetting resins used in the composites industry are unsaturated polyesters, epoxies, vinyl esters and phenolics. There are differences between these groups that must be understood to choose the proper material for a specific application.

5.4.2(a) Polyester

Unsaturated polyester resins (UPR) are the workhorse of the composites industry and represent approximately 75% of the total resins used. To avoid any confusion in terms, readers should be aware that there is a family of thermoplastic polyesters that are best known for their use as fibers for textiles and clothing. Thermoset polyesters are produced by the condensation polymerization of dicarboxylic acids and difunctional alcohols (glycols). In addition, unsaturated
polyesters contain an unsaturated material, such as maleic anhydride or fumaric acid, as part of the dicarboxylic acid component. The finished polymer is dissolved in a reactive monomer such as styrene to give a low viscosity liquid. When this resin is cured, the monomer reacts with the unsaturated sites on the polymer converting it to a solid thermoset structure.

A range of raw materials and processing techniques are available to achieve the desired properties in the formulated or processed polyester resin. Polyesters are versatile because of their capacity to be modified or tailored during the building of the polymer chains. They have been found to have almost unlimited usefulness in all segments of the composites industry. The principle advantage of these resins is a balance of properties (including mechanical, chemical, and electrical) dimensional stability, cost and ease of handling or processing.

Unsaturated polyesters are divided into classes depending upon the structures of their basic building blocks. Some common examples would be orthophthalic (“ortho”), isophthalic (“iso”), dicyclopentadiene (“DCPD”) and bisphenol A fumarate resins. In addition, polyester resins are classified according to end use application as either general purpose (GP) or speciality polyesters.

Polyester producers have proved willing and capable of supplying resins with the necessary properties to meet the requirements of specific end use applications. These resins can be formulated and chemically tailored to provide properties and process compatibility.

5.4.2(b) Epoxy

Epoxy resins have a well-established record in a wide range of composite parts, structures and concrete repair. The structure of the resin can be engineered to yield a number of different products with varying levels of performance. A major benefit of epoxy resins over unsaturated polyester resins is
their lower shrinkage. Epoxy resins can also be formulated with different materials or blended with other epoxy resins to achieve specific performance features. Cure rates can be controlled to match process requirements through the proper selection of hardeners and/or catalyst systems. Generally, epoxies are cured by addition of an anhydride or an amine hardener as a 2-part system. Different hardeners, as well as quantity of a hardener produce a different cure profile and give different properties to the finished composite.

Epoxies are used primarily for fabricating high performance composites with superior mechanical properties, resistance to corrosive liquids and environments, superior electrical properties, good performance at elevated temperatures, good adhesion to a substrate or a combination of these benefits. Epoxy resins do not however, have particularly good UV resistance. Since the viscosity of epoxy is much higher than most polyester resin, requires a post –cure (elevated heat) to obtain ultimate mechanical properties making epoxies more difficult to use. However, epoxies emit little odor as compared to polyesters.

Epoxies are used with a number of fibrous reinforcing materials, including glass, carbon and aramid. This latter group is of small in volume, comparatively high cost and is usually used to meet high strength and/or high stiffness requirements. Epoxies are compatible with most composite manufacturing processes, particularly vacuum-bag molding, autoclave molding, pressure -bag molding, compression molding, filament winding and hand lay up.

5.4.2(c) Vinyl Ester

Vinyl esters were developed to combine the advantages of epoxy resins with the better handling/faster cure, which are typical for unsaturated polyester resins. These resins are produced by reacting epoxy resin with acrylic or methacrylic
acid. This provides an unsaturated site, much like that produced in polyester resins when maleic anhydride is used. The resulting material is dissolved in styrene to yield a liquid that is similar to polyester resin. Vinyl esters are also cured with the conventional organic peroxides used with polyester resins. Vinyl esters offer mechanical toughness and excellent corrosion resistance. These enhanced properties are obtained without complex processing, handling or special shop fabricating practices that are typical with epoxy resins.

5.4.2(d) Phenolic

Phenolics are a class of resins commonly based on phenol and formaldehyde. Phenolics are thermosetting resins that cure through a condensation reaction producing water that should be removed during processing. Pigmented applications are limited to red, brown or black. Phenolic composites have many desirable performance qualities including high temperature resistance, creep resistance, excellent thermal insulation and sound damping properties and corrosion resistance. Phenolics are applied as adhesives or matrix binders in engineered woods (plywood), brake linings, clutch plates and circuit boards.

5.4.2(e) Polyurethane

Polyurethane is a family of polymers with widely ranging properties and uses, all based on the exothermic reaction of an organic polyisocyanates with a polyols (an alcohol containing more than one hydroxyl group). A few basic constituents of different molecular weights and functionalities are used to produce the whole spectrum of polyurethane materials. The versatility of polyurethane chemistry enables the polyurethane chemist to engineer polyurethane resin to achieve the desired properties.
Polyurethanes appear in an amazing variety of forms. They are used as a coating, elastomer, foam or adhesive. When used as a coating in exterior or interior finishes, polyurethane’s are tough, flexible, chemical resistant and fast curing.

The resins in thermoset composites are an important source of properties and process characteristics. One of the great design strengths of composites is the multiple choices of resins. In order to make effective use of these choices, designers and product specifiers should be familiar with the properties, advantages and limitations of each of the common composite resins. It is common to use the resources of the resin manufacturers’ laboratories to determine the best resin or an application.

In the present investigation unsaturated polyester resins are used as matrix materials for the preparation of composites.

5.4.3 Additives and Modifiers

A wide variety of additives are used in composites to modify materials properties and tailor the laminate’s performance. Although these materials are generally used in relatively low quantity by weight compared to resins, reinforcements and fillers, they perform critical functions. Additive used in thermoset and thermoplastic composites include the following:

5.4.3(a) Low shrink/low profile

When parts with smooth surfaces are required a special thermoplastic resin which moderates resin shrinkage, can be added to thermoset resins.
5.4.3(b) Fire resistance

Combustion resistance is improved by proper choice of resin, use of fillers or flame retardant additives. Included in this category are materials containing antimony trioxide, bromine, chlorine, borate and phosphorus.

5.4.3(c) Air release

Most laminating resins, gel coats and other polyester resins might entrap air during processing and application. This can cause air voids and improper fiber wet-out. Air release additives are used to reduce such air entrapment and to enhance fiber wet-out.

5.4.3(d) Emission control

In open mold applications, styrene emission suppressants are used to lower emissions for air quality compliance.

5.4.3(e) Viscosity control

In many composite types, it is critical to have a low, workable viscosity during production. Lower viscosity in such filled systems is usually achieved by use of wetting and dispersing additives. These additives facilitate the wet-out and dispersion of fillers resulting in lower viscosity (and/or higher filler loading).

5.4.3(f) Electrical conductivity

Most composites do not conduct electricity. It is possible to obtain a degree of electrical conductivity by the addition of metal, carbon particles or conductive fibers. Electromagnetic shielding can be achieved by incorporating conductive materials.
5.4.3(g) **Toughness**

It can be enhanced by the addition of reinforcements. It can also be improved by special additives such as certain rubber or other elastomeric materials.

5.4.3(h) **Antioxidants**

Plastics are sometimes modified with antioxidants, which retard or inhibit polymer oxidation and the resulting degradation of the polymer.

5.4.3(i) **Antistatic agents**

Antistatic agents are added to polymers to reduce their tendency to attract electrical charge. Control of static electricity is essential in certain plastics processing and handling operations, as well as in finished products. Static charges on plastics can produce shocks, present fire hazard and attract dust. The effect of static charge in computer/data processing applications is particularly detrimental.

5.4.3(j) **Foaming agents**

Foaming agents are chemicals that are added to polymers during processing to form minute cells throughout the resin. Foamed plastics exhibit lower density, decrease material costs, improve electrical and thermal insulation, increase strength-to-weight ratio and reduce shrinkage.

5.4.3(k) **Plasticizers**

Plasticizers are added to compounds to improve processing characteristics and offer a wider range of physical and mechanical properties.
5.4.3(l) Slip and blocking agents

It provides surface lubrication. This results in reduced coefficient of friction on surfaces and enhances release of parts from the mold.

5.4.3(m) Heat stabilizers

Heat stabilizers are used in thermoplastic systems to inhibit polymer degradation that results from exposure to heat.

5.4.3(n) Ultraviolet stabilizers

UV stabilizers are used in both thermoset and thermoplastic composites to prevent loss of gloss, crazing, chalking, discoloration, changes in electrical characteristics, embrittlement and disintegration due to ultraviolet (UV) radiation. Additives, which protect composites by absorbing the UV, are called ultraviolet absorbers. Materials, which protect the polymer in some other manner, are known as ultraviolet stabilizers.

5.4.4 Catalysts, Promoters, Inhibitors

In polyesters, the most important additive is catalyst or initiator. Typically, organic peroxide such as methylethylketone peroxide (MEKP) is used for room temperature cured processes or benzoyl peroxide is added to the resin for heat -cured molding. When triggered by heat or used in conjunction with a promoter (such as cobalt napthanate), peroxides convert to a reactive state (exhibiting free radicals), causing the unsaturated resin to react (cross -link) and become solid. Some additives such as TBC (tertiary butyl catechol) are used to slow the rate of react ion and are called inhibitors. Accelerators such as DMA (dimethyl aniline) speed up the curing.
5.5 VARIOUS PROCESSING METHODS OF COMPOSITES

In many cases, polymer composite processing utilizes the same technique as polymer processing which include injection molding, compression molding and extrusion. There are other techniques which are unique only to polymer composite processing. These include filament winding, pultrusion, and hand lay-up. Inspite of the fact that some techniques are used commonly with polymer processing, the operational conditions can be very different; thus, it is important not to directly transfer knowledge without careful consideration. Various processing methods are listed as below.

5.5.1 Hand Lay-up Molding
5.5.2 Spray-up Molding
5.5.3 Compression Molding, Transfer Molding and Resin Transfer Molding
5.5.4 Injection Molding
5.5.5 Reaction Injection Molding
5.5.6 Pultrusion
5.5.7 Filament Winding

5.6 COMPOSITE FABRICATION

Two basic methods are generally used for the fabrication of composites, which are known as wet and dry lay-up lamination. Wet lay-up method implies the use of liquid resins to impregnate the matrix material either before or after it has been laid in place. In case of conventional dry-up method the reinforcement is impregnated with a solution of the resin in appropriate solvent and the solvent evaporated or flushed off and the result is dry resin impregnated sheet known as a prepreg which is used to prepare composites [80]. Laminating is normally carried out manually by brush, roller or squeezer application to glass fiber [81]. The composites were made by using glass fiber and various resin systems. In present study
the compositions used for the composites preparation are shown in Table - 5.1 to 5.3.

The resin composition containing styrene as cross linking agent and benzoyl peroxide as a catalyst and applied to 6 × 6 inch square pieces of jute with brush. The solvent allowed to evaporate at 50°C. The dried eight prepregs prepared in this way were stacked one over another and pressed between two plates using Teflon sheets as mould releasing agent. The plates were compressed under 95-100 psi at specified temperature (110-110°C) and then kept in an oven maintained at required temperature for two hours. The composites so obtained were cooled to room temperature before releasing the pressure. All the composites were prepared by the same procedure. The specimens for testing were made by cutting the composites and matching them to required final dimensions. All the tests were conducted according to ASTM methods.

<table>
<thead>
<tr>
<th>Sample UPR &amp; SDUPR (60%)</th>
<th>Jute (40%) in gms</th>
<th>SDUPR (60%) in gms</th>
<th>Total Weight in gms</th>
<th>BPO (2% of total Wt) in gms</th>
<th>Cureing Temp. in °C</th>
<th>Cureing time in hrs.</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2</td>
</tr>
<tr>
<td>S11</td>
<td>35.40</td>
<td>53.10</td>
<td>88.50</td>
<td>1.77</td>
<td>100-110</td>
<td>2</td>
</tr>
<tr>
<td>S12</td>
<td>35.15</td>
<td>52.73</td>
<td>87.88</td>
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<tr>
<td>S13</td>
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<td>88.41</td>
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<tr>
<td>S14</td>
<td>35.03</td>
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<td>1.75</td>
<td>100-110</td>
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<tr>
<td>S15</td>
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<td>47.88</td>
<td>79.80</td>
<td>1.60</td>
<td>100-110</td>
<td>2</td>
</tr>
</tbody>
</table>

Table: 5.1 Composition of composites
### Table: 5.2 Composition of composites

<table>
<thead>
<tr>
<th>Sample</th>
<th>Jute (40%) in gms</th>
<th>SDUPR (60%) in gms</th>
<th>Total Weight in gms</th>
<th>BPO (2% of total Wt) in gms</th>
<th>Cureing Temp. in °C</th>
<th>Cureing time in hrs.</th>
</tr>
</thead>
<tbody>
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<td>36.70</td>
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<td>91.75</td>
<td>1.85</td>
<td>100-110</td>
<td>2</td>
</tr>
<tr>
<td>S23</td>
<td>35.08</td>
<td>52.56</td>
<td>87.66</td>
<td>1.75</td>
<td>100-110</td>
<td>2</td>
</tr>
<tr>
<td>S24</td>
<td>35.30</td>
<td>52.95</td>
<td>88.25</td>
<td>1.77</td>
<td>100-110</td>
<td>2</td>
</tr>
<tr>
<td>S25</td>
<td>34.40</td>
<td>51.60</td>
<td>86.00</td>
<td>1.72</td>
<td>100-110</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table: 5.3 Composition of composites

<table>
<thead>
<tr>
<th>Sample</th>
<th>Jute (40%) in gms</th>
<th>SDUPR (60%) in gms</th>
<th>Total Weight in gms</th>
<th>BPO (2% of total Wt) in gms</th>
<th>Cureing Temp. in °C</th>
<th>Cureing time in hrs.</th>
</tr>
</thead>
<tbody>
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<td>35.73</td>
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<td>1.82</td>
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<tr>
<td>S33</td>
<td>35.88</td>
<td>53.82</td>
<td>89.70</td>
<td>1.79</td>
<td>100-110</td>
<td>2</td>
</tr>
<tr>
<td>S34</td>
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<td>86.10</td>
<td>1.72</td>
<td>100-110</td>
<td>2</td>
</tr>
<tr>
<td>S35</td>
<td>35.56</td>
<td>53.34</td>
<td>88.90</td>
<td>1.78</td>
<td>100-110</td>
<td>2</td>
</tr>
</tbody>
</table>

#### 5.7 MECHANICAL PROPERTIES OF COMPOSITES

The mechanical properties, among all the properties of plastic materials are often the most important properties because virtually all service conditions for the majority of end-use application involve some degree of mechanical loading. The material selection for a variety of application is quite often based on mechanical properties such as tensile...
strength, flexural strength, flexural modulus, elongations strength and impact strength. In the current study, following tests were performed to characterize composites for the mechanical properties according to American Standard for Testing Material (ASTM). The test includes measurement of flexural strength, Izod impact strength and hardness of composites. These testing parameter are briefly described below.

5.7.1 **Flexural properties**

It is one of the most important mechanical properties of interest for any comparison of rigid materials or modulus of rupture. Flexural properties are useful for quality control and specific purpose. In addition, they serve to classify material with respect to their bending strength and stiffness characteristics. The stress strain behavior of polymers is of interest to a designer as well as a polymer manufacture.

Flexural strength is the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. The stress induced due to flexural load is combination of compressive and tensile stress. Flexural properties are reported and calculated in terms of the maximum stress and strain that occur at the outside surface of the test bar.

Many polymers do not break under flexure after a large deflection. This makes determination of the ultimate flexural strength impractical for those polymers. In such cases, the common practice is to report flexural yield strength when the maximum strain in the outer fiber of the specimen has reached 5%. For polymeric material that a break easily under flexural load, the specimen is deflected until a rupture occurs in the outer fibers. Generally two basic methods that cover the determination of flexural properties are as follows:
**Method I**

Three point loading system utilizing center loading on a simply supported beam.

**Method II**

Four point loading system utilizing two load points equally spaced from their adjacent support points, with a distance between load points of either one third or one half of the support span.

Method II is very useful in testing material that does not fail at the point of maximum stress under a three-point loading system (method I).

The rest specimens were conditioned in accordance with the method I of ASTM D 790 (1971).

A study of flexural properties was carried out in terms of stress-strain relationship according to standard method of testing ASTM D-790 [82]. A Dutron's Tensile Tester Model No. 130 was used in the present study. For the measurement, a strip of the dimensions 8.0 x 1.25 cm$^2$ was cut from the laminate. It suited the gauge length of 7.5 cm i.e. the experiment was carried out a distance between two jaws to be 7.5 cm apart. The results were recorded with the chart speed of 2 mm/min at room temperature. The test was initiated by applying the load to the specimen at the specified crosshead rate. The deflection was measured by gauge under the specimen in contact with it in the center of the support span. Flexural strength was calculated by the following calculations and the results are included in Table -5.4 to 5.6

The maximum fiber stress was related to the load and sample dimensions and was calculated using the following equation.

\[ S = \frac{3PL}{2bd^2} \]

............... (5.1)
Where $S = \text{stress}$,

$P = \text{load of the moment of break.}$

$L = \text{length of span.}$

$b = \text{width of specimen.}$

$d = \text{thickness of specimen.}$

Flexural strength is equal to the maximum stress in the outer fibers at the moment of break. This value can be calculated by using equation 5.1.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>FLEXURAL STRENGTH</th>
<th>FLEXURAL MODULAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>425.44</td>
<td>6412.58</td>
</tr>
<tr>
<td>S11</td>
<td>570.77</td>
<td>7508.46</td>
</tr>
<tr>
<td>S12</td>
<td>330.50</td>
<td>5019.25</td>
</tr>
<tr>
<td>S13</td>
<td>260.49</td>
<td>3708.56</td>
</tr>
<tr>
<td>S14</td>
<td>205.50</td>
<td>2827.24</td>
</tr>
<tr>
<td>S15</td>
<td>198.06</td>
<td>2816.68</td>
</tr>
</tbody>
</table>

Table: 5.4 Flexural Strength & Flexural Modulas (kg/cm$^2$)

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>FLEXURAL STRENGTH</th>
<th>FLEXURAL MODULAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>425.44</td>
<td>6412.58</td>
</tr>
<tr>
<td>S21</td>
<td>2065.27</td>
<td>26528.68</td>
</tr>
<tr>
<td>S22</td>
<td>1875.25</td>
<td>25022.54</td>
</tr>
<tr>
<td>S23</td>
<td>1824.12</td>
<td>23416.43</td>
</tr>
<tr>
<td>S24</td>
<td>1806.80</td>
<td>20025.00</td>
</tr>
<tr>
<td>S25</td>
<td>1802.12</td>
<td>20008.00</td>
</tr>
</tbody>
</table>

Table: 5.5 Flexural Strength & Flexural Modulas (kg/cm$^2$)
Table: 5.6 Flexural Strength & Flexural Modulus (kg/cm²)

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>FLEXURAL STRENGTH</th>
<th>FLEXURAL MODULAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>425.44</td>
<td>6412.58</td>
</tr>
<tr>
<td>S31</td>
<td>820.87</td>
<td>20312.47</td>
</tr>
<tr>
<td>S32</td>
<td>604.25</td>
<td>8040.26</td>
</tr>
<tr>
<td>S33</td>
<td>455.87</td>
<td>6502.78</td>
</tr>
<tr>
<td>S34</td>
<td>400.56</td>
<td>5488.61</td>
</tr>
<tr>
<td>S35</td>
<td>365.00</td>
<td>5002.91</td>
</tr>
</tbody>
</table>

5.7.2 Impact properties

The impact properties of the polymeric materials are directly related to the overall toughness of the material. Toughness is defined as the ability of the polymer to absorb applied energy. The area under the curve is directly proportional to the toughness of the material. The higher the impact strength of the material, the higher the toughness and vice versa. Impact resistance is the ability of a material to resist breaking under a shock loading or the ability to resist the fracture under stress applied at high speed.

Most polymers, when subjected to the impact loading, seem to fracture in a characteristic fashion. The crack is initiated on a polymer surface due to the impact loading. The energy to initiate such crack is called the crack initiation energy. If the load exceeds the crack initiation energy, the crack continues to propagate. A complete failure occurs when the load has exceeded the crack propagation energy. Thus, both crack initiation and propagation contribute to the measurement of impact strength. There are basically four types of failure encountered due to the impact load. They are listed below.

(a) Brittle fracture
(b) Sight cracking
(c) Yielding failure
(d) Ductile failure

However, the distinction between the four types of failures is not very clear and some overlap is quite possible.

In the last two decades, a tremendous amount of time and money have been spent on research and development of various types of impact tests by organizations throughout the world. Attempts have been made to develop different sizes and shapes of specimens as well as impact testers. Impact load has been applied using anything from a hammer, punches and pendulums to falling balls and bullets.

An impact test can be divided into six major classes and subdivided into many different types having slight variations.

(I) Pendulum impact tests.
   (a) Izod impact test
   (b) Charpy impact test
   (c) Chip impact test
   (d) Tension impact test

(ii) High rate tensile test

(iii) Falling weight impact test
   (a) Pro weight (tup) impact test

(iv) Instrumented impact test

(v) High rate impact tests
   (a) High-speed ball impact tests.
   (b) High-speed plunder impact tests.

(vi) Miscellaneous impact tests.

Out of the above tests, the Izod impact test was performed in the current study. A brief detail about the test is presented below.

5.7.2(a) Izod impact test

The objective of the Izod impact test is to measure the relative susceptibility of a standard test specimen to the pendulum type impact load. The results are expressed in
terms of kinetic energy consumed by the pendulum in order to break the specimen. The energy required to break a standard specimen is actually the sum of energies needed to deform it, to initiate its fracture and to propagate the fracture across it, and the energy needed to throw the broken ends of the specimen. This is called the “toss factor”. The energy lost through the friction and vibration of the apparatus is minimum and common for all practical purposes and generally neglected.

The specimen used in Izod tests is usually notched. The reason for notching the specimen is to provide a stress concentration area that promotes a brittle rather than ductile failure. Izod test requires a specimen to be clamped vertically as a cantilever beam. The specimen is struck by swing of a pendulum hammer released from a fixed distance from the specimen clamp. If the specimen does not break, more weights are attached to the hammer and the test should be repeated until failure is observed. The impact values are read directly in joule, In- lbs or ft - lbs from the scale.

The impact strength is calculated by dividing the impact values by the thickness of the specimen as depicted in equation 5.2

\[
\text{Izod impact strength} = \frac{R}{d} \quad ........... (5.2)
\]

Where \( R \) = energy required to break the specimen.

\( d \) = thickness of the specimen.

A study on Izod impact strength was carried out in terms of resistance to breakage under high velocity impact conditions, according to ASTM D-256[83].

Zwick model No. 8900 Impact Machine was used for the present study. For the measurement, a specimen was cut from the fabricated composite (6.4 x 1.27 cm\(^2\)) and V notched (2.5 mm) at the middle. The test specimen was clamped into position so that notched end of the specimen remained facing the striking edge of pendulum. The impact test indicates the
energy to break standard test specimen of specified size under the stipulated conditions of specimen mounting and pendulum velocity at impact. All the measurements were carried out at room temperature. The impact strength was calculated by using equation 5.2. The data are presented in the Table 5.7 to 5.9.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>RESULT IN J/Cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>1.60</td>
</tr>
<tr>
<td>S11</td>
<td>1.84</td>
</tr>
<tr>
<td>S12</td>
<td>1.75</td>
</tr>
<tr>
<td>S13</td>
<td>1.72</td>
</tr>
<tr>
<td>S14</td>
<td>1.65</td>
</tr>
<tr>
<td>S15</td>
<td>1.63</td>
</tr>
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</table>

**Table: 5.7 Impact Strength (J/Cm²)**

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>RESULT IN J/Cm²</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1.60</td>
</tr>
<tr>
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<td>2.64</td>
</tr>
<tr>
<td>S22</td>
<td>2.25</td>
</tr>
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<td>1.92</td>
</tr>
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<td>S24</td>
<td>1.51</td>
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<tr>
<td>S25</td>
<td>1.25</td>
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**Table: 5.8 Impact Strength (J/Cm²)**

<table>
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</thead>
<tbody>
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<td>2.50</td>
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<tr>
<td>S34</td>
<td>2.12</td>
</tr>
<tr>
<td>S35</td>
<td>2.03</td>
</tr>
</tbody>
</table>

**Table: 5.9 Impact Strength (J/Cm²)**
5.7.3 Hardness test

Hardness of a material is defined as the resistance to deformation, particularly permanent deformation, indentation or scratching. Hardness test can differentiate relative hardness of different grade of a particular plastic. However, it is not valid to compare hardness of various types of plastics entirely on the basis of one type of test. Since elastic recovery along with hardness is important. The test is further complicated by a phenomenon such as creep. Many tests have been devised to measure the hardness. Since plastic materials vary considerably with respect to hardness, one type of hardness test is not applicable to cover the entire range of hardness properties encountered. Two of the most commonly used hardness tests for plastics are the Rockwell hardness test and the Durometer hardness test. Rockwell hardness is used for relatively hard plastics and for soft materials, Durometer hardness is often used.

5.7.3(a) Rockwell hardness

The Rockwell hardness test measures the net increase in depth impression as the load on an indentor is increased from a fixed minor to a major load and then returned to minor load. Generally the Rockwell hardness numbers derived are just the numbers without unit. Rockwell hardness numbers are always quoted with a scale symbol representing the indicator size, load and the dial scale. The hardness scales in order of increasing hardness are L, M and P scales. The higher the number in each scale, the harder is the material. There is a slight overlap of hardness scale and therefore, it is quite possible to obtain two different dial readings on different scales for the same material. For a specific type of material, correlation in the overlapping regions is possible. However due to differences in elasticity, creep and shear
characteristics between different plastics, a general correlation is not possible.

The Rockwell hardness study was carried out at room temperature according to standard method of testing ASTM D–785 [84].

In the present study, Rockwell hardness tester model RAS/Saroj Engg. Udyog Pvt. Ltd., Jaysingpur was used. Load of 100kgf was applied for each measurement. The specimen with parallel flat surfaces was placed on the avail of the apparatus and minor load (10kgf) was applied by lowering the steel ball onto the surface of the specimen. The dial was adjusted to zero on the scale under minor load and the major load (100kgf) was immediately applied by releasing the trip lever. After 15 second the major load was removed and the specimen was allowed to recover for 15 second. Rockwell hardness was read directly on the dial with the minor load still applied. The obtained results of Rockwell hardness of composites are reported in Table 5.10 to 5.12.

<table>
<thead>
<tr>
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<tr>
<td>S11</td>
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<tr>
<td>S12</td>
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</tr>
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Table: 5.10 Rockwell Hardness
Table: 5.11 Rockwell Hardness

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<td>S22</td>
<td>126</td>
</tr>
<tr>
<td>S23</td>
<td>135</td>
</tr>
<tr>
<td>S24</td>
<td>139</td>
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<td>S25</td>
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Table: 5.12 Rockwell Hardness

<table>
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<td>95</td>
</tr>
<tr>
<td>S32</td>
<td>74</td>
</tr>
<tr>
<td>S33</td>
<td>35</td>
</tr>
<tr>
<td>S34</td>
<td>25</td>
</tr>
<tr>
<td>S35</td>
<td>20</td>
</tr>
</tbody>
</table>

5.8 JUTE COMPOSITE DEGRADATION METHOD

20 gm of the jute composites were taken in each 1000 ml flask containing sterile mineral medium (pH-7). To it 10% vv of culture suspension of isolated BS₃ were added. All the flasks were kept on shaker (150rpm) and after 40 days all flask was removed and analysed for dry weight.

BS₃ was found to be maximum amylase producer and hence was used for studies. BS₃ is gram positive motile, nonspore forming bacilli. Results are shown in Tables with BS₃, loss in dry weight.
### Table: 13 Percentage Degradation Of AAMUPR- Jute Composites

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>DEGRADATION (PERCENTAGE)</th>
<th>DURATION (DAYS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>5%</td>
<td>40</td>
</tr>
<tr>
<td>S11</td>
<td>6%</td>
<td>40</td>
</tr>
<tr>
<td>S12</td>
<td>6%</td>
<td>40</td>
</tr>
<tr>
<td>S13</td>
<td>7%</td>
<td>40</td>
</tr>
<tr>
<td>S14</td>
<td>8%</td>
<td>40</td>
</tr>
<tr>
<td>S15</td>
<td>9%</td>
<td>40</td>
</tr>
</tbody>
</table>

### Table: 14 Percentage Degradation Of FAMUPR- Jute Composites

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>DEGRADATION (PERCENTAGE)</th>
<th>DURATION (DAYS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>5%</td>
<td>40</td>
</tr>
<tr>
<td>S21</td>
<td>5%</td>
<td>40</td>
</tr>
<tr>
<td>S22</td>
<td>6%</td>
<td>40</td>
</tr>
<tr>
<td>S23</td>
<td>7%</td>
<td>40</td>
</tr>
<tr>
<td>S24</td>
<td>7%</td>
<td>40</td>
</tr>
<tr>
<td>S25</td>
<td>9%</td>
<td>40</td>
</tr>
</tbody>
</table>

### Table: 15 Percentage Degradation Of LAMUPR- Jute Composites

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>DEGRADATION (PERCENTAGE)</th>
<th>DURATION (DAYS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>5%</td>
<td>40</td>
</tr>
<tr>
<td>S31</td>
<td>8%</td>
<td>40</td>
</tr>
<tr>
<td>S32</td>
<td>10%</td>
<td>40</td>
</tr>
<tr>
<td>S33</td>
<td>12%</td>
<td>40</td>
</tr>
<tr>
<td>S34</td>
<td>14%</td>
<td>40</td>
</tr>
<tr>
<td>S35</td>
<td>17%</td>
<td>40</td>
</tr>
</tbody>
</table>

Table: 15 Percentage Degradation Of LAMUPR- Jute Composites
**Figure- 5.1** Weight loss of UPR (S1) & AAMUPR (S11 to S15) - jute composites.

**Figure- 5.2** Weight loss of UPR (S1) & FAMUPR (S21 to S25) - jute composites.

**Figure- 5.3** Weight loss of UPR (S1) & FAMUPR (S31 to S35) - jute composites.
Figure- 5.4 Infrared spectra of UPR-S1
<table>
<thead>
<tr>
<th>No.</th>
<th>Group</th>
<th>IR Characteristics (cm(^{-1}))</th>
<th>IR for UPR-S1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Esters α,β - unsaturated &gt;C=O stretching</td>
<td>1730 – 1715</td>
<td>1729.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>C-H Stretching in aromatic</td>
<td>~3030</td>
<td>2985.19</td>
</tr>
<tr>
<td>C</td>
<td>C-C multiple bend stretching in aromatic</td>
<td>~1600</td>
<td>1600.16</td>
</tr>
<tr>
<td>D</td>
<td>Hydrocarbon Alkane –CH(_2)-</td>
<td>1445-1485</td>
<td>1454.35</td>
</tr>
<tr>
<td>E</td>
<td>Alcohols O-H bond stretching</td>
<td>1260-1350</td>
<td>1283.63</td>
</tr>
<tr>
<td>F</td>
<td>C-H stretching in aromatic ring (O-disubstituted)</td>
<td>735-770</td>
<td>743.78</td>
</tr>
</tbody>
</table>

**Table-5.16 Anticipated IR spectral features**
Figure- 5.5 Infrared spectra of AAMUPR-S11
<table>
<thead>
<tr>
<th>No.</th>
<th>Group</th>
<th>IR Characteristics (cm(^{-1}))</th>
<th>IR for UPR-S1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Esters α,β - unsaturated &gt;C=O stretching</td>
<td>1730 – 1715</td>
<td>1728.00</td>
</tr>
<tr>
<td>B</td>
<td>C-H Stretching in aromatic</td>
<td>~3030</td>
<td>3025.10</td>
</tr>
<tr>
<td>C</td>
<td>C-C multiple bend stretching in aromatic</td>
<td>~1600</td>
<td>1605.60</td>
</tr>
<tr>
<td>D</td>
<td>Hydrocarbon Alkane –CH(_2)-</td>
<td>1445-1485</td>
<td>1456.30</td>
</tr>
<tr>
<td>E</td>
<td>Alcohols O-H bond stretching</td>
<td>1260-1350</td>
<td>1285.66</td>
</tr>
<tr>
<td>F</td>
<td>C-H stretching in aromatic ring (O-disubstituted)</td>
<td>735-770</td>
<td>748.70</td>
</tr>
</tbody>
</table>

**Table-5.17 Anticipated IR spectral features**
Figure- 5.6 Infrared spectra of FAMUPR-S21
<table>
<thead>
<tr>
<th>No.</th>
<th>Group</th>
<th>IR Characteristics (cm⁻¹)</th>
<th>IR for FAMUPR-S21</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Esters α,β - unsaturated &gt;C=O stretching</td>
<td>1730 – 1715</td>
<td>1730.37</td>
</tr>
<tr>
<td>B</td>
<td>C-H Stretching in aromatic</td>
<td>~3030</td>
<td>2984.27</td>
</tr>
<tr>
<td>C</td>
<td>C-C multiple bend stretching in aromatic</td>
<td>~1600</td>
<td>1601.24</td>
</tr>
<tr>
<td>D</td>
<td>Hydrocarbon Alkane –CH₂-</td>
<td>1445-1485</td>
<td>1453.83</td>
</tr>
<tr>
<td>E</td>
<td>Alcohols O-H bond stretching</td>
<td>1260-1350</td>
<td>1282.91</td>
</tr>
<tr>
<td>F</td>
<td>C-H stretching in aromatic ring (O-disubstituted)</td>
<td>735-770</td>
<td>743.84</td>
</tr>
</tbody>
</table>

**Table-5.18 Anticipated IR spectral features**
Figure- 5.7 Infrared spectra of LAMUPR-S31
<table>
<thead>
<tr>
<th>No.</th>
<th>Group</th>
<th>IR Characteristics (cm(^{-1}))</th>
<th>IR for FAMUPR-S21</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>A</strong> Esters (\alpha,\beta) - unsaturated (&gt;\text{C}=\text{O}) stretching</td>
<td>1730 – 1715</td>
<td>1727.34</td>
</tr>
<tr>
<td></td>
<td><strong>B</strong> C-H Stretching in aromatic</td>
<td>~3030</td>
<td>2985.78</td>
</tr>
<tr>
<td></td>
<td><strong>C</strong> C-C multiple bend stretching in aromatic</td>
<td>~1600</td>
<td>1601.84</td>
</tr>
<tr>
<td></td>
<td><strong>D</strong> Hydrocarbon Alkane –CH(_2)-</td>
<td>1445-1485</td>
<td>1452.82</td>
</tr>
<tr>
<td></td>
<td><strong>E</strong> Alcohols O-H bond stretching</td>
<td>1260-1350</td>
<td>1286.83</td>
</tr>
<tr>
<td></td>
<td><strong>F</strong> C-H stretching in aromatic ring (O-disubstituted)</td>
<td>735-770</td>
<td>743.39</td>
</tr>
</tbody>
</table>

**Table-5.19 Anticipated IR spectral features**
5.9 RESULTS AND DISCUSSION

The IR spectra of cured unsaturated polyester resins are as shown in Fig. 5.4. The data regarding the IR spectral characteristics presented in Table 5.16 reveals that small variations in the location of the peaks due to absorptions by functional groups like –CH\(_2\) and C=O are observed depending upon the structure of the diols/ anhydrides/ acids.

For UPR-S1, a strong absorption band at 743.78 cm\(^{-1}\) can be attributed to –C-H stretching in aromatic ring (O-disubstituted). Spectrum absorption bend at 1729.00 cm\(^{-1}\) & 2985.19 cm\(^{-1}\) confirms the presence of \(\alpha,\beta\)-unsaturated >C=O bond in ester linkage & C-H stretching in aromatic respectively. Absorption peak does not appear at 1652 cm\(^{-1}\) for C-C multiple bond stretching in alkene after curing of UPR-S1, so it was missing in Table 5.16. Spectrum absorption bend at 1600.16 cm\(^{-1}\) was C-C multiple bend stretching in aromatic. Alkane –CH\(_2\)- & O-H bond stretching was confirmed by the presence of bend at 1454.35 cm\(^{-1}\) and 1283.63 cm\(^{-1}\) respectively.

For AAMUPR-S11, a strong absorption band at 748.70 cm\(^{-1}\) can be attributed to –C-H stretching in aromatic ring (O-disubstituted). Spectrum absorption bend at 1728.00 cm\(^{-1}\) & 3025.10 cm\(^{-1}\) confirms the presence of \(\alpha,\beta\)-unsaturated >C=O bond in ester linkage & C-H stretching in aromatic respectively. Absorption peak does not appear at 1655 cm\(^{-1}\) for C-C multiple bond stretching in alkene after curing of AAMUPR-S21, so it was missing in Table 5.17. Absorption peak appearing at 1605.60 cm\(^{-1}\) was C-C multiple bend stretching in aromatic. Alkane –CH\(_2\)- & O-H bond stretching was confirmed by the presence of bend at 1456.30 cm\(^{-1}\) and 1285.66 cm\(^{-1}\) respectively.

For FAMUPR-S21, a strong absorption band at 743.84 cm\(^{-1}\) can be attributed to –C-H stretching in aromatic ring (O-
disubstituted). Spectrum absorption bend at 1730.37 cm\(^{-1}\) & 2984.27 cm\(^{-1}\) confirms the presence of \(\alpha,\beta\)-unsaturated >C=O bond in ester linkage & C-H stretching in aromatic respectively. Absorption peak dose not appearing at 1650.50 cm\(^{-1}\) for C-C multiple bond stretching in alkene after curing of FAMUPR-S21, so it was missing in Table 5.18. Absorption peak appearing at 1601.24 cm\(^{-1}\) was C-C multiple bend stretching in aromatic. Alkane –CH\(_2\)- & O-H bond stretching was confirmed by the presence of bend at 1453.83 cm\(^{-1}\) and 1282.91 cm\(^{-1}\) respectively.

For LAMUPR-S31, a strong absorption band at 743.39 cm\(^{-1}\) can be attributed to –C-H stretching in aromatic ring (O-disubstituted). Spectrum absorption bend at 1727.34 cm\(^{-1}\) & 2985.78 cm\(^{-1}\) confirms the presence of \(\alpha,\beta\)-unsaturated >C=O bond in ester linkage & C-H stretching in aromatic respectively. Absorption peak dose not appearing at 1658.55 cm\(^{-1}\) for C-C multiple bond stretching in alkene after curing of LAMUPR-S31, so it was missing in Table 5.19. Absorption peak appearing at 1601.84 cm\(^{-1}\) was C-C multiple bend stretching in aromatic. Alkane –CH\(_2\)- & O-H bond stretching was confirmed by the presence of bend at 1452.82 cm\(^{-1}\) and 1286.83 cm\(^{-1}\) respectively.

Unsaturated polyester resin (UPR-S1) compared with modified unsaturated polyester resin. Flexural Strength & Flexural Modulas of AAMUPR-S11 (adipic acid modified unsaturated resin) is greater than UPR-S1. For AAMUPR-S12 to AAMUPR-S15 the Flexural Strength & Flexural Modulas are lower than UPR-S1. The Flexural Strength & Flexural Modulas of FAMUPR-S21 to FAMUPR-S25 are decreases but they higher than UPR-S1. In case of LAMUPR-S31 to LAMUPR-S33, the Flexural Strength & Flexural Modulas are higher than UPR-S1. But, the properties again lower for LAMUPR-S34 & LAMUPR-S35 than UPR-S1.
The Impact Strength of all modified unsaturated polyester resin are decreases if moles of Adipic, Fumaric and Lactic acid increases but the Impact Strength of all modified unsaturated polyester resin are higher than the unsaturated polyester resin (UPR-S1), except FAMUPR-S24 & S25.

The Rockwell Hardness of AAMUPR and FAMUPR are higher than UPR-S1. For LAMUPR, the Rockwell Hardness is greater than UPR-S1 (only for Sample S31 & S32). But the properties again lower for LAMUPR-S33 to LAMUPR-S35 than UPR-S1.

In case of jute composites, the result of biodegradation test indicates that the all modified unsaturated polyester resin made jute composites are more degrade than the unsaturated polyester resin made composite. The composite degradation percentage indicates that the best result obtain for lactic acid modified unsaturated polyester resin made composites than the other modified unsaturated polyester resin composites. For LAMUPR-S31 to LAMUPR-S35, the moles of lactic acid increases and the moles of Phthalic anhydride decreases and composite degradation percentage increases.
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