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PROPERTIES OF MULTI-WALLED CARBON NANOTUBES/WOVEN KENAF/WOVEN GLASS REINFORCED EPOXY LAMINATED COMPOSITES

By

Mohd Hafizi Bin Mohamad

Supervisor: Profesor Dr. Ir. Mariatti Bt. Jaafar @ Mustapha

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled "**properties of multi-walled carbon nanotubes/woven kenaf/woven glass reinforced epoxy laminated composites**". I also declare that is has not been previously submitted for the award of any degree or diploma or other or other similar title of this for any other examining body or University.

Name of Student: Mohd Hafizi Bin Mohamad Signature:

Date: 4 July 2017

Witness by

Supervisor: Profesor Dr. Ir. Mariatti Bt. Jaafar @ Mustapha Signature:

Date: 4 July 2017

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UNIT

°C	Degree Celsius
%	Percentage
g/cm^3	density
MPa	Mega Pascal
GPa	Giga Pascal
g	gram
mm^2	Unit of area

ABBREVIATIONS

CNT	Carbon nanotube
MWCNT	Multi-welled carbon nanotubes
KF	Kenaf
GF	Glass Fiber
FRPC	Fiber reinforcement polymer composites.

ABSTRAK

Gentian tetulang komposit epoksi berlapis telah digunakan secara meluas dalam pelbagai aplikasi. Tujuan kajian ini adalah untuk mengkaji kesan karbon tiub nano berbilang (MWCNT) dinding dalam kenaf anyaman komposit berlapis. Tenunan kenaf/epoksi komposit dengan MWCNT dan tanpa MWCNT telah direka menggunakan kaedah beg vakum. 1 vol% MWCNT telah dimasukkan ke dalam komposit laminat tenunan kenaf/epoksi menggunakan teknik semburan dan larutan. Ujian lenturan tiga titik telah digunakan untuk menilai sifat-sifat lenturan sampel komposit dengan dan tanpa MWCNT yang disediakan oleh dua teknik tersebut. Keputusan itu disokong oleh pemerhatian morfologi. Pemerhatian morfologi pada permukaan patah komposit mendedahkan bahawa kegagalan delaminasi berlaku dalam komposit laminat MWCNT/tenunan kenaf/epoksi yang disediakan dengan kaedah semburan. Didapati bahawa penambahan MWCNT menggunakan kedua-dua teknik semburan dan teknik larutan telah mengurangkan kekuatan lenturan dan modulus lenturan MWCNT/tenunan kenaf/epoksi, dengan trend pengurangan yang jelas ditunjukkan oleh teknik semburan. Kajian lanjut pada komposit hibrid menunjukkan bahawa komposit hibrid laminat MWCNT/tenunan kaca/tenunan kenaf/epoksi mempamerkan peningkatan sebanyak 44% kekuatan lenturan dan modulus lenturan berbanding komposit laminat MWCNT/kenaf tenunan/epoksi.

PROPERTIES OF MULTI-WALLED CARBON NANOTUBES/WOVEN KENAF/WOVEN GLASS REINFORCED EPOXY LAMINATED COMPOSITES

ABSTRACT

The fiber reinforcement epoxy laminated composites have been widely used in many applications. The aim of this study is to investigate the effect of multi-welled carbon nanotubes (MWCNT) addition in woven kenaf epoxy laminated composites. Woven kenaf/epoxy composites with and without MWCNT were fabricated using vacuum bagging. 1 vol % MWCNT was added into woven kenaf/epoxy laminated composite using spraying and solution method. Flexural test was employed to evaluate the flexural properties of the composite samples. The results were supported by morphological observation. The morphological observation of the composites fracture surface revealed that delamination failure occurred in MWCNT/woven kenaf/epoxy laminated composite prepared by spraying method. Regardless number of ply in the composites laminates both spraying and solution method decrease the flexural strength and flexural modulus of MWCNT/woven kenaf/epoxy composites. Density results show that addition of MWCNT in composites laminate reducing the weight of woven kenaf/epoxy laminated composites. Further investigation on hybrid composites showed that MWCNT/woven glass/woven kenaf/epoxy laminated hybrid composites exhibited 44% flexural strength and modulus increase compared to MWCNT/woven kenaf/epoxy laminated composites respectively

CHAPTER 1

INTRODUCTION

1.1 Background

Natural fibres are more and more being thought about and believed as a new renewable material in substituting ordinary and non-renewable materials (such as glass, carbon and aramid fibres). Natural fibres such as hemp, flax, jute, sisal, kenaf, banana and pineapple leaves offer (more than two, but not a lot of) advantages including good mechanical properties (high clearly stated/particular strength and modulus), low density, good thermal behavior, easy to obtain and degradable and easy to create. Moreover, natural fibers will be an acceptable comparator to synthetic fibers, like glass, in many ecological characteristics however not in respect of mechanical strength (Zhu *et al.*, 2013).

The applications of natural fibers area unit growing in several sectors such as piece of furniture, construction, vehicles and packing because of their low cost, low weight and fewer harm compared to synthetic fibers. However, significant enhancements within the strength of chemical compound composites may be achieved whereas reinforcing naturalfibers under completely different conditions. In spite of those promising options shown by natural fibres sure major drawbacks are underlined like water absorption, strength degradation, lack in thermal stability lowered impact properties; however, it is been found that these will be improved and overcome by hybridizing with either natural or synthetic fibre (Domun *et al.*, 2015).

In composite applications natural fibers have shown to be competitive in relation to glass fiber natural fibre reinforced composites with thermoset matrices have

successflly proven their qualities in varied fields of application. The growing interest in victimization natural fibers as reinforcement of polymer-based composites is principally attributable to their accessibility from renewable natural resources, satisfactorily high specific strength and modulus, lightweight weight, low price and biodegradability (Poostforush and Fasihi, 2013).

The biodegradability of the natural fibers might gift a healthy system whereas the low prices and good performance of those fibers can fulfill the economic interest of industry. But still the mechanical strength of a natural fiber reinforced epoxy composites could not match that of a synthetic fiber reinforced epoxy composites and the natural fibers would not replace synthetic fibers in all applications. For the last decades, in depth analysis is afoot to boost the mechanical properties of natural fiber reinforced epoxy composites, while the intrinsic properties of the natural fibers like biodegradability and low specific gravity of the fibers stay unchanged.

Recently, the quickly increasing use of composite elements in automotive, construction, sports and leisure, and alternative production industries, has been targeted on property and renewable strengthened composites (Zhu *et al.*, 2013). This interest encompasses a good form of shapes and materials starting from synthetic to natural, to meet the stress of manufacturing composites with desired properties. The incorporation of reinforcements, like fibers and fillers into composites affords a way of extending and rising the properties of the composites that meets the necessities of most engineering applications.

Consequently, these enhancements are going to be related to economic blessings, like low production prices and low organic compound consumption (Ariawan *et al.*, 2015).Thus, stress for fibre strengthened composites have inflated drastically over

the past few years, for varied business applications within the industrial sector. The reinforcing capability of the fibres principally influenced by varied aspects like polarity of the fibre, mechanical strength of the fibres, surface appearances, and existence of reactive centres (Sengupta *et al.*, 2007).

Carbon nanotubes are added into compound matrix to enhance the stiffness, strength, toughness, dimensional stability and thermal properties (Jumahat *et al.*, 2012) However, the properties of those nanocomposite depend on various factors like dispersion of nanofillers, the compatibility of the nanofillers with polymer matrix and the surface bonding of nanofillers with polymer matrix. Agglomerate particles and poor dispersion of nanofillers introduce premature failure of the nanocomposites system.

Previous study about modification of composites has been made to the polymer matrix by integrating with the nanofillers such as CNT, graphene and nanoclays (Domun *et al.*, 2015). The addition nanofiller was increase the properties of the fiber reinforced epoxy composites by flexural strength and modulus. When introduced CNT to the reinforcement composite also help fiber reinforced epoxy composites improve the properties such as lightweight and high strength as reported by wet spreading, solvent spraying technique (Gandhi and Polytechnic, 2014).

1.2 Problem Statement

The shortage of fuel supply and also the new imperative of environmental property to combat warming have exerted tremendous pressure on reworking the present materials design and producing technologies for human transportation. Light-weight is quickly changing into a necessity for structures, as a result of its less energy consumption from the vehicles that take into consideration of this important issue. Whereas plastic and composite materials are employed in vehicles nowadays, they represent solely more or less 7.5% of total vehicle mass and the applications are usually not for the first vehicle structure (Poostforush and Fasihi, 2013).

Fabrication of fiber and synthetic fibers to produce hybrid composites is an innovatively method and able to increase the properties (Mahdi *et al.*, 2003). Hybrid composites are composed of over one sort of reinforcement and that they are often classified into interplay or laminated hybrid, interply or tow-by-tow hybrid, intimately mixed hybrid, and different styles of mixtures. Since the mechanical properties of natural and hybrid and the surface properties between reinforcement and matrix dissent greatly, the hybridization effects would vary too for the hybrid composites.

Natural fiber can develop high mechanical properties at low density compared to synthetic fiber but there are some weakness that make natural fiber not been used commerciality. On the opposite hand, natural fibers do not seem to be free from issues and that they have notable deficits in properties. The natural fibers structure consists of cellulose, hemicelluloses, lignin, pectin, and waxy substances and permits wet absorption from the environment that causes weak bindings between the fiber and

polymer. Moreover, the couplings between fibre and chemical compound are considered a challenge as a result of the chemical structures of each fibers and matrix are varied. These reasons for ineffectual stress transfer throughout the interface of the made composites. Consequently, natural fiber modifications using specific treatments are necessary. As a result, fiber modifications cause reduction of wet absorption of the natural fibers that cause a superb enhancement incompatibility between the fiber and polymer matrix (Gandhi and Polytechnic, 2014).

In this research, hybrid composite was developed by 2 combining synthetic fiber and MWCNT filler. Synthetic fiber combined with natural fiber form a laminated hybrid reinforcement epoxy composite. Previous research by Hamza et al. (2016) reported that, the mechanical properties of synthesized composites are higher than those of natural fabric composites. According to the results obtained, the hybrid jute/glass reinforcement is sufficiently stiff and strong to be introduced in composite laminates with thermosetting matrix

For the filler addition in fiber reinforcement epoxy composite, the result obtained from this study reported by Saba et al, (2015) is encouraging as the fabricated hybrid nanocomposites prepared by nano Oil palm empty fruit bunchfiller and kenaf fibers shows improved mechanical properties without additional coupling agent and treatment of kenaffibers. The addition of nano OPEFBiller in the kenaf/epoxy composites signi cantly improved the mechanical strength in terms of tensile, impact strength and elongation at break compared to the conventional kenaf fibers reinforced epoxy composites by hindering the crack initiation or propagation paths

1.3 Research Objectives

(1) To determine flexural properties woven kenaf / woven glass epoxy laminated composites

(2) To compare the effect of Multi-Walled Carbon Nanotubes (MWCNT) addition on the flexural properties of woven kenaf laminated composite by using spraying and solution methods.

(3) To evaluate effect of MWCNT addition on woven glass/ woven kenaf epoxy hybrid laminated composites.

CHAPTER 2

LITERATURE REVIEW

2.1 Thermoset Polymer

Thermoset materials are those materials that are created by polymers joined along by chemical bonds, exploit an extremely crosslinked polymer structure. The extremely crosslinked structure made by chemical bonds in thermosetting materials, is directly chargeable for the high mechanical and physical strength high strength to support high stress or load and temperature compared with thermoplastics or elastomers materials. On the opposite hand thermoset highly crosslinked structure that provides a poor elasticity or elongation of this materials.

Thermosetting resin rheology are often studied using each dynamic periodic tests and steady shear. The primary section of the consistence varies of a thermosetting are often characterized with steady shear measurements. The stiffened sample eventually tears or fractures. As the reaction advances to the gel point and on the far side, the organic compound's consistence measuring is often performed till the resin becomes a stiff solid (Assaad, 2017). This are often possible because the measurements can be created at a strain amplitude that is low enough to stop gel structure disruption throughout its formation.

Figure 2.1 shows the comparison between steady shear viscosity information and dynamic viscosity data for a hardening epoxy resin. It is necessary to be ready to measure viscosity throughout the thermosetting curing reaction although it offers solely a partial image of the development going down. Physical property information is needed

to finish the characterization owing to viscoelastic nature of the material. These are nonheritable in a very dynamic check coinciding with consistence measuring.

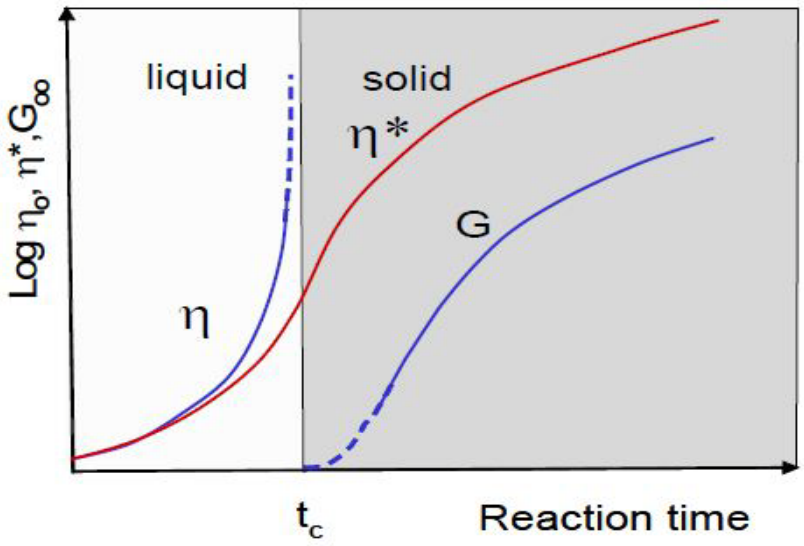

Figure 2.1: Measurement of the viscosity of a curing epoxy resin (Azom et al,.2013)

2.1.1 Epoxy

Resins are used for several years in an exceedingly multitude of commercial product, like structural automotive adhesives, high performance fibre reinforced composites, electrical and electronic applications, serious duty protecting coatings and lots of a lot of. However they are terribly brittle and thus in most business formulations toughеners are used. Epoxy resins were discovered in 1909 by Prileschajew (Sprenger, 2014). Epoxy resins are defined as low-molecular-weight pre-polymers containing more than one epoxide group of the form.

Epoxy resins are thermoset resins, which are cured using a wide range of curing agents via curing reactions. Their properties rely upon the particular combination of the sort of epoxy resins and set agents used because of their glorious mechanical properties, high adhesiveness to several substrates, and smart heat and chemical resistances,

presently epoxy resins area unit intensively used across a good vary of fields, wherever they act as fiber-reinforced materials, all-purpose adhesives, superior coatings, and encapsulating materials(Assaad, 2017)

The term "epoxy resin" describes a broad class of thermosetting polymers in which the primary cross linking occurs through the reaction of an epoxide group. In general, an epoxy resin can be thought of as a molecule containing a three-membered ring, consisting of one oxygen atom and two carbon atoms. While the presence of this functional group defines a molecule as an epoxide, the molecular base to which it is attached can vary widely, yielding various classes of epoxy resins. The commercial success of epoxies is due in part to the diversity of molecular structures that can be produced using similar chemical processes.

In combination with judicious selection of a curing agent and appropriate modifiers, epoxy resins can be specifically tailored to fit a broad range of applications. It is important to understand basic production techniques to appreciate the available resins and how they differ from each other. Epoxy resins are produced from base molecules containing an unsaturated carbon-carbon bond. There are two processes that can be used to convert this double bond into an oxirane ring: dehydrohalogeriation of a halohydrin intermediate and direct peracid epoxidation. While both processes are used to produce commercial epoxy resins, the halohydrin route is more common and is used to produce a wider variety of materials (Liu *et al.*, 2012).

2.1.2 Unsaturated Polyester

Unsaturated polyester resins are made by chemical reaction of saturated and unsaturated di-carboxylic acids with alcohols. Unsaturated polyester resins type extremely durable structures and coatings after they are cross-linked with a vinyl reactive monomer, most ordinarily styrene. The properties of the cross-linked unsaturated polyester resins rely on the categories of acids and glycols used and their relative proportions. Unsaturated polyester resins are further classified into the following categories as shown in Table 2.1

Table 2.1: Category of unsaturated polyester resin (Liu *et al.*, 2012).

Type of Resin	Properties
Ortho-phthalic polyesters	Resins made from ortho-phthalic anhydride are generally cheaper than the other two classes of unsaturated polyester resins. They are usually used to manufacture general purpose composite laminates where only moderate structural properties are required.
Iso-phthalic polyesters	Resins made from Iso-phthalic acid. These resins are much more structurally competent than the ortho-phthalic resins. They also have superior corrosion resistance and are used for more demanding applications
Tere-phthalic polyesters	Tere-phthalate resins are made from tere-phthalic acid. These resins are currently made in small volumes and are considered a specialty resin.

2.2 Nanoparticulate fillers

In order to outline nanometre scale things (10^{-9}m) the term nano is employed. A nanometre is, therefore, equivalent to the billionth of a meter, or 80,000 times thinner than a person's hair. The nanometre vary covers sizes smaller than the wavelength vary of light however larger than many atoms (Kamel, 2007). Nanomaterials are classified into 3 groups; nanotubes, nanoparticles, and nanolayers, depending on the quantity of measurements of the phase that are in the nanometer range Nano-particles considered the vital potential filler materials for the enhancement of physical and mechanical properties of compound matrix (Njuguna et al., 2007).

The distinctive nanometric size, capable of manufacturing huge and huge specific surface areas, even over a 1000 m^2/g, in conjunction with their different distinctive properties currently shows thorough analysis activities within the fields of engineering and natural sciences (Njuguna et al., 2007). Nanofillers possess tendency to enhance or regulate the altered or variable properties of the materials into which they are incorporated, like incombustible properties, optical or electrical properties, mechanical and thermal properties, considerably, generally in synergism with standard or ancient fillers. Nanofillers are incorporated in compound matrices at rates from a hundred and twenty fifth to 100% (in mass). The various nanofillers that are employed in nano composites are nanoclays, nano-oxides, carbon nanotubes, and organic nanofillers.

An addition of reinforcements (fibers, fillers, particles, whiskers, etc.) could be a methodology for increasing the bulk mechanical/physical properties in several materials. In most cases, the potency of reinforcing fillers in composites is reciprocally proportional to the scale and directly proportional to the filler extent to volume magnitude relation. Nanoparticles area unit presently thought of as a high-potential filler material for the development of mechanical and physical properties of compound

composites (Njuguna et al., 2008). Experiments have shown that compared to microparticles, nanoparticles confer some distinctive options to compound composites.

The massive surface area possess nanofillers promotes higher surface interactions with the compound matrix, leading to better property sweetening (Hanim *et al.*, 2008). Natural fiber reinforcement composites and nanocomposites area unit a lot of environmentally friendly, hence, a lot of oft applied to assembling and construction industries (partition boards, ceiling paneling), transportation (automobiles, railway coaches, part packaging, consumer products), etc. crossing involving the mixture of nanofiller and fibre within the matrix results reduction of water-absorption properties and increased in mechanical properties (Borba et al., 2014).

2.2.1 Properties of CNTs

The mechanical, thermal and electrical conductivities of the CNTs vary depending on CNTs fabrication method as well as the testing or characterization methods. Table 2.1 shows physical and mechanical properties of SWCNTs and MWCNTs. CNTs have been introduced as the most promising nanofillers in the composites as well as nanocomposites (Lee and Jeong, 2014). Owing to their excellent properties, they have been applied widely in many fields such as actuators, sensors, electronic devices, structural reinforcement and etc (Qian *et al.*, 2002; Li *et al.*, 2008; Yee *et al.*, 2014). Several ways have been used to incorporate the CNTs in those composites. Methods of dispersing of CNTs in the composites are discussed in the next sub-section.

Table 2.1: Physical and mechanical properties of SWCNTs and MWCNTs (Ma *et al.*, 2010; Ma and Kim, 2011).

Property	CNTs	
	SWCNT	MWCNT
Specific gravity (g/cm^3)	0.8	1.8
Strength (GPa)	13-54	4-63
Young's Modulus (TPa)	0.32-8.3	0.27-1.8
Electrical conductivity (S/cm)	10^2-10^6	10^3-10^5
Electron mobility ($cm^2/(Vs)$)	~10^5	10^4-10^5
Thermal conductivity (W/(mK))	6000	2000
Thermal stability in air (°C)	>600	>600

2.2.2 Dispersion of CNTs in polymer

Incorporation of CNTs in polymer has been proved to enhance the properties of polymer matrix. Commonly, integration of CNT in polymers was normally carried out with the aid of mechanical dispersion such as ultrasonication. Dispersion of CNTs in polymers only allows interaction between the CNTs and the surrounding polymer matrix via the van der Waals bonding (Ma and Kim, 2011). The weak van der Waals interaction probably may hinder the efficient CNT-matrix load transfer (Ma and Kim, 2011; Yang *et al.*, 2012). The performance of the CNT nanocomposites is highly depending on the CNT dispersion and the CNT-matrix interfacial interactions. Therefore in fabrication of CNT/polymer nanocomposites, dispersion of CNTs in solvents or functionalization was performed prior to physical mixing of CNTs into the polymer (Ma and Kim, 2011).

One the polymer binders often chosen are epoxy resin. The epoxy resins are formed by the reaction between a multi-epoxy monomer and a diamine or anhydride hardener (Biron, 2004). Choices of multi epoxy available include DGEBA, DGEBD, TGAP and TGMDA whereas hardeners available are aliphatic, cycloaliphatic or aromatic diamines. The curing behaviour of the epoxy is depending on the type of hardener chosen. The usage of aliphatic amines reduces the curing temperature hence lower the glass transition temperature whereas aromatic amines produced resin with higher curing and glass transition temperature (Biron, 2004).

Epoxides are widely used in numerous applications such as automotive industries, aeronautical, space and armaments, shipbuilding, water sports and sport industries, anti-corrosion, anti-wear and protection properties industries and etc (Biron, 2004; Yang *et al.*, 2012). One of the reasons that made the epoxides to be chosen in such wide applications is due to the variety and easy processing method. Generally, epoxy provides excellent mechanical properties with broad range of moduli, have the ability of adherence on wide selection of substrates and good resistance against several organic solvent and other chemicals (Biron, 2004). Furthermore certain grades of epoxy promote good thermal and electrical properties. Basically it can be said that epoxy resin are often chosen due to low viscosity, low creep, able to provide better adhesion to several substrates with high strength as well experience low shrinkage throughout the curing process (Zulfli and Shyang, 2010).

2.3 Fiber reinforced epoxy composites

For the past many years, Fiber reinforced epoxy composites materials are being thought-about for replacement the metallic parts in aviation, armed service automotive and aircraft industries (Botelho *et al.*, 2006). Compared to metal, fiber reinforced epoxy

composites have denseness, higher specific strength and stiffness, higher corrosion resistance and improved fatigue performance. Performance of those composite below numerous loading condition; like axial, torsional and impact loading is extremely crucial for the planning of structural parts.

Mechanical properties of fiber reinforcement epoxy composites rely upon the fiber, matrix and therefore the interface between them. Researchers are investigating numerous organic and inorganic nanoparticles as reinforcement of composites to reinforce the mechanical properties and thermal stability. Important development within the use of nanoparticles for modification of epoxy matrix has light-emitting diode to improve mechanical properties of the fiber reinforced epoxy composites.

2.3.1 Kenaf fiber reinforced epoxy composites

Kenaf is relatively commercially offered and economically cheap amongst different natural fibre reinforcing material. Usually kenaf denoted as industrial kenaf because of of its great interest for the assembly of business raw materials. Kenaf fibre belongs to species of hibiscus cannabinus where genus is mallow and Malvaceae obtained from stems of plants (Salleh *et al.*, 2012), that includes cotton (Gossypium spp.) and okra (Abelmoschus esculentus L. Moench). Kenaf is wild dicotyledons plant of subtropic and tropical elements of Africa and Asia. Kenaf could be a hardy, robust and difficult plant with a fibrous stalk, immune to insect injury and needs comparatively fewer quantity of or no pesticides. Kenaf is compliant to many styles of soils and to grow effectively, want solely nominal chemical treatment, characteristically some chemical and one weed killer treatment.

The 3 styles offiber: bast, core, and pith cons titutes the kenaf plant (Karimi *et al.*, 2014). However, kenaf is characterised by 2 distinct fiber bast and core comprising thirty fifth and sixth fifth severally. The bark and core fiber, thought of as 2 distinct styles of raw material which will be distinguished by their chemical composition anatomical appearances (Khalil *et al.*, 2010). The pith contains entirely of parenchymatous cells that are polygonal in form not generally prismatic. In keeping with researchers, the kenaf bast fiber possess putting mechanical properties that build them as a replacement to glass fiber in polymer composites as reinforcing elements. Fiber length, fiber content, and fiber orientation of kenaf fiber affects physical and mechanical properties of kenaf fiber reinforced soy primarily based bio composites.

Kenaf fibre extensively being used in engineering fields, as fibre in fibre reinforced polymer composite sector. Kenaf exhibits several salient options like low feedstock, high biomass content, and negligible pesticides requirement alongside low, crop rotation. The prime benefit of the crop rotation by the kenaf is that the contribution towards the weeds control, immune to drought and add diversity to the dry land, and therefore the control of soybean nematode. Kenaf fibres displayed improved and enticing properties in compound composites as reinforcement materials at a lower place flexural loading circumstances in comparison to the connected form of others natural fibres. Thereby generating a chance of work the artificial (synthetic) fibres like glass and aramid with kenaf fibres for flexural structural and non-structural applications. Table 2.2 shown properties of woven kenaf fiber.

Table 2.2: The properties of woven kenaf fiber (Mohanty et al., 2005).

Properties		**Values**
Chemical Composition	lignin (%)	20.1
	Cellulose (%)	44.4
	Ash (%)	4.6
Tensile modulus (GPa)		40
Ultimate stress (MPa)		350-600
Elongation at break (%)		2.5-3.5
Density		1.45

2.3.2 Glass fiber reinforced epoxy composites

Glass fiber-reinforced epoxy composite was most commonly utilized in the manufacture of composite materials. The matrix comprised organic, polyester, thermostable, vinylester, phenolic and epoxy resins. The mechanical behaviour of a fiber-reinforced composite primarily depends on the fiber strength and modulus, the chemical stability, matrix strength and the interface bonding between the fiber/matrix to modify stress transfer (Paukszta et al., 2013). Appropriate compositions and orientation of fibers created desired properties and useful characteristics of glass fiber-reinforced epoxy composite composites was equal to steel, had higher stiffness than aluminium and the specific gravity was one-quarter of the steel. Various GF reinforcements like long longitudinal, woven mat, sliced fiber (distinct) and sliced mat in the composites are made to boost the mechanical and tribological properties of the composites.

The properties of composites rely on the fibers laid or laminated within the matrix throughout the composites preparation. High price of polymers was a limiting

factor in their use for industrial applications. Due to that the employment of fillers improved the properties of composites and ulitimately reduced the price of the preparation and product. Composite materials have wide range of commercial applications and laminated GF reinforced composite materials are utilized in marine industry and piping industries owing to sensible environmental resistance, higher harm tolerance for impact loading, high specific strength and stiffness (Kumar *et al.*, 2009) .Polymeric composites were principally utilised in craft industries like rudder, elevator, fuselage, landing gear doors, that's because of light-weight weight, reduction of higher fatigue resistance within the fasteners and variety of elements.

2.3. 3 Hybrid fiber reinforced epoxy composites

In light of those findings, hybrid composites are developed by combining 2 kinds of fibers, that are from low elongation and high elongation fibers. This can be to keep up the prevalence and moderate the disadvantage of each fibers. Recently, variety of analysis studies are dole out to boost the properties moreover as scale back the price of the fiber reinforcement epoxy composites. This can be accomplished through replacement of some of carbon fibers with glass fibers (Poyyathappan *et al.*, 2014). Their study indicated that the enduringness of the hybrid composites performed higher than woven fiber reinforcement epoxy composites. Besides that, Zhang *et al.*, (2012) conducted analysis on the tensile, flexural and compressive responses of plain-woven hybrid composites by using totally different arrangement and glass/carbon magnitude relation. The results showed that the ratios of glass/carbon FRP composites in 50:50 have improved the tensile, flexural and compressive strength effectively

2. 4 Hybrid fiber-particulate filler reinforced polymer composite

Natural fiber shows relatively poor fiber/matrix interactions, water resistance, and comparatively lower sturdiness. The weaker surface or adhesion bonds between extremely hydrophilic natural fibers and hydrophobic, non-polar organophilic polymer matrix, results in significant decrease within the properties of the composites and, thus, considerably obstructs their industrial utilization and production. However, many approaches and schemes are established to supplement this deficiency in compatibility, together with the introduction of coupling agents and numerous surface modification techniques. The surface of the natural fibers will be changed and this may be achieved by physical, mechanical, and chemical suggests that. For any composite, the circumstances for substantial reinforcement and virtuous properties are the solid distribution of the reinforcing element, orientation, smart adhesion, and comparatively high ratio.

Nano-particles are presently thought of as a high-tension filler materials for the development of mechanical and physical properties of compound composites (Njuguna et al., 2009) because the nano scale fillers are typically freed from defects, hence, their applications within the field of compound composite space setup, new trends of prospect to overwhelm the restrictions of traditional/conventional micrometer scale. High matrix-filler surface space produces a uniform and solid dispersion of nanoparticles are liable for dynamic relaxation, moreover in succeeding the mechanical, molecular quality, and thermal properties (Schadler et al., 2007). Generally, nano sized filler present within the minor zone whereas solely few of the small particles participate within the plastic zone deformation. This provides the simplest way for the nanofillers to enhance fracture and mechanical properties of the matrix having brittle property. Nanofillers that possess bigger ratio of significant interest, and, thus, show higher

reinforcement for the nanocomposites production. Nanofillers are usually incorporated on a weight basis for the nanocomposite development. The composite properties are greatly influenced by the precise expanse of nano fillers that shows uninterrupted influence.

Hybrid composite developed by various researchers (Njuguna et al., 2009), by combining natural fibers/natural fiber and natural fibers/synthetic fibers with epoxy, polyester, phenolic, poly vinyl organic compound, poly ester resins, etc., area unit well established. The environmental awareness attracted researchers to develop new composites with addition of over one reinforcement from natural resources, like natural fiber/natural fiber or natural fiber/nanofiller from organic sources as an alternate to synthetic fibers (Sathishkumar *et al.*, 2013). Hybridization involving the mixture of nanofiller and fiber within the matrix results reduction of water absorption properties and increased in mechanical properties. Many analysis works depicts of these facts. The mechanical and thermal properties of rice husk flour/high density polyethylene composites get improved by addition of small amount of nanoclay. Mechanical and tribological performance of the date palm fiber/epoxy composites get increased by addition of graphite filler however high content of the graphite deteriorates the mechanical properties. Natural fiber/nanofiller-based hybrid composites are often utilised in building and construction materials, transportation (automobiles, railway coaches, part packaging, client merchandise, etc., and conjointly may well be attainable to supply acoustic non-conductor and intensely thermally stable materials.

2.5 Fabrication of fiber reinforced epoxy composite

Composite laminate is a combination of fiber and resin mixed in correct form. One of the the distinctive properties of composite laminate is that it has high specific

strength. Composites are being used as viable alternatives to metallic materials in structures wherever weight is a major thought, e.g., part structures, high speed boats and trains. Composite fabrication processes involve molding, to form the resin and reinforcement. A mold tool is needed to provide the unformed resin /fiber combination its form before and through cure. For an outline of mold types and materials and methods used to build mold tools. The most basic fabrication technique for thermosetting composites is hand lay-up, which generally consists of laying dry fabric layers, or “plies,” or prepreg plies, by hand onto a tool to create a laminate stack. Resin is applied to the dry plies once lay-up is complete (e.g., by means that of rosin infusion). During a variation referred to as wet lay-up, every ply is coated with resin and “debulked” or compacted once it's placed.

Several curing methods are reported and themost basic is just to permit cure to occur at temperature (Zhang et al., 2009). Cure will be accelerated, however, by applying heat, usually with an oven, and pressure, by means that of a vacuum. For the latter, a vacuum bag, with breather assemblies, is placed over the lay-up and hooked up to the tool, then evacuated employing an air pump before cure. The vacuum material method consolidates the plies of fabric and considerably reduces voids because of the off-gassing that happens because the matrix progresses through its chemical hardening stages. Non-uniform curing can lead to incomplete cure or resin degradation and entrapped volatiles or voids, which may ultimately cause a reduction in the overall quality and in service performance of the finished component.

Many superior thermosetting elements need heat and high consolidation pressure to cure conditions that need the utilization of an autoclave. Autoclaves, generally, area unit expensive to shop for and operate. Makers that are equipped with autoclaves sometimes cure variety of elements at the same time. Computer systems monitor and

control autoclave temperature, pressure, vacuum and inert atmosphere, that permits unattended and/or remote direction of the cure method and maximizes efficient use of the technique.

2.5.1 Hand lay-up

In the present study the composite laminate specimens are prepared using the hand layup technique and the specimen are subjected to the investigation is carried out as per the ASTM standards. The simplest manufacturing technique adopted involved laying down bidirectional type fibers over a polished mould surface previously treated with a releasing agent: after this, a liquid thermosetting resin is worked into the reinforcement by hand with a brush or roller. The process is repeated several times equal to the number of layers required for the final composite. Resin and curing agents are pre-mixed and normally designed to cross-link and harden at room temperature. The major advantage of this manufacturing process is its great flexibility, meaning that it suits most common mould sizes and complex shapes. It can be re-used for several runs and the actual cost of the raw materials make this process economically feasible.

2.5.2 Vacuum bagging

Vacuum bagging was used to make the laminates fiber reinforcement epoxy composite. Vacuum bag moulding uses a flexible film to enclose the part and seal it from outside air. A vacuum is then drawn on the vacuum bag and atmospheric pressure compresses the part during the cure. Vacuum bag material is available in a tube shape or a sheet of material. Vacuum level was monitored so as to avoid surface undulations and also avoid air pockets at the interface. Vacuum hand lay – up process offers many

benefits when compared to conventional hand lay-up techniques. As it is a closed moulding process, it virtually eliminates potentially harmful volatile organic compound (VOC) emissions. The vacuum system also facilitates good resin distribution and consolidation of the laminate. As a result, the mechanical properties of the laminates are likely to be higher than the case with hand laminating.

In vacuum bagging method, vacuum pressure was utilized in order to force the polymer to impregnate through the buckypaper. In the study performed by Ashrafi *et al.* (2010) and Chapartegui *et al.* (2012), the polymer binder was placed over the surface of the buckypaper prior to vacuum bagging or autoclave procedure. Figure 2.7 illustrates the vacuum bagging procedure carried out to enable impregnation of the polymer binder through the buckypaper. Release films were placed on top and bottom of the buckypaper to ease the peeling-off process after the vacuum bagging process. The polymer filled-buckypaper was then cured in the oven (Ashrafi *et al.*, 2010; Chapartegui *et al.*, 2012).

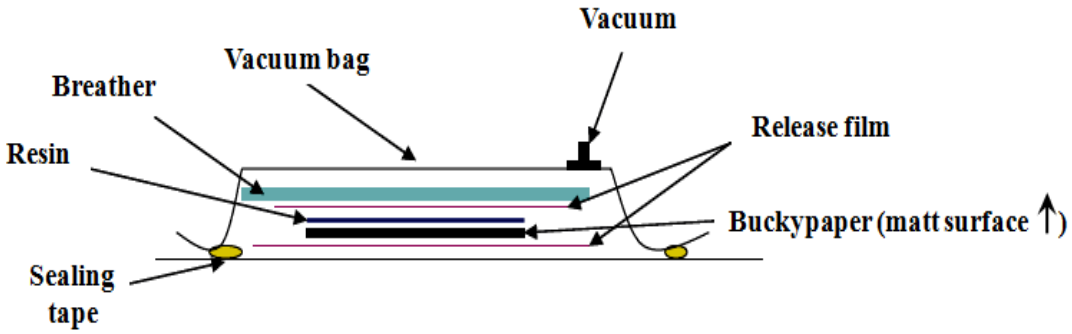

Figure 2.2: Vacuum bagging procedure carried out to enable impregnation of the polymer binder through the buckypaper (Chapartegui *et al.*, 2012)

2.5.3 Solution Mixing

Judging from its capability to fabricate small sample sizes CNT/polymer nanocomposites, solution mixing method has been widely chosen in the fabrication of nanocomposites (Kanoun *et al.*, 2014). This method which is frequently used to

fabricate thin films involves three major steps (Ma *et al.*, 2010). This method begins with dispersion of CNTs in solvent by mechanical mixing. The solvent also can be used to dissolve the polymer matrix. The solution produced was then mixed thoroughly by implementing mechanical or magnetic agitation or ultrasonication. The homogenously dispersed CNT will be finally mixed with the polymer at room or elevated temperature. The nanocomposites are attained by casting in a mould (Thostenson *et al.*, 2001), spin coating and etc.

2.5.4 Combination of hand or spray lay-up with vacuum bag moulding

Often, the hand or spray lay-up process will be continue with vacuum or pressure bag moulding before curing process. Figure 2.10 illustrates the principle of the vacuum bag moulding utilized after hand or spray lay-up. Anti-adherent vacuum bag film is placed on top of the composite's surface prior to vacuum process. As the vacuum applies on the system creates compression onto the composite. After that, the curing procedure will be carried out.