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Study of Polymer Matrix Composite with Natural Particulate/Fiber in PMC: A Review

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Abstract: The evolution of composite material has replaced most of the conventional material used for automobile, aviation and another area of construction. Moreover, in the field of the composite, a rapid growth has been noticed in the area of natural reinforced composite material. The reason behind this growth in the research field of natural reinforced composite is the advantages of them over the other reinforcement, such as low cost, and lower environmental impact. This paper gives a review of some of the developments with a discussion of the problems with the present generation natural reinforced composites and prospects for further developments. Various physical and mechanical properties of natural reinforced polymer matrix composite have been studied with the combination of different natural reinforcement with the polymer matrix. The issues discussed relate to the mechanical properties in general, environmental degradation and long-term durability. The aim of this review is to provide an overview of the properties, development, and performance of natural reinforced polymer matrix composite.

Keywords: Polymer Matrix Composite, Particulate.

1. INTRODUCTION

Polymer matrix composites (PMC's) are being used basically for aerospace industry but the decrement in the price of carbon fibres with time as well as the developments of low-cost reinforcement like natural fiber, has increased the applications of these composites in the area of automobile, marine, sports, biomedical, construction, and other industries also. PMC's are having excellent properties like lightweight, high stiffness, high strength, good corrosion resistance, lesser environmental degradation, excellent thermal insulation, good acoustic damping and non-magnetic properties [Boopalan M et. al. (2013), Fiore V et. al. (2016), Sarikanat M et.al. (2014), etc].

This literature review is related to the characterization of natural reinforced polymer composite materials, a different type of natural reinforcement used in the polymer composites, mechanical properties, and manufacturing process of polymer composite etc. Over the recent decades, the use of natural reinforcement in place of synthetic reinforcement in the fabrication of PMC's has attracted great attention. The properties of natural fibers such as huge availability, low cost, renewability, low density, higher modulus, and biodegradability make them suitable to develop composite materials combining with polymer matrix [Ku H et.al. (2011), Premalal et.al. (2002)]. Effect of water absorption on the mechanical properties of natural reinforced polymer matrix composite has been studied and the effect of chemical treatment of the reinforcement has also been analysed. The development of natural hybrid PMCs is growing rapidly due to the high performance in mechanical properties, significant processing advantages, low cost and low density. Also natural fiber composite produced lower emission of toxic fumes when they are heated during their working life and during incineration at end of life

Natural fibers are renewable resources in many countries of the world; they are cheaper, pose no health hazards and provide a solution to environmental pollution by finding a new use for waste materials from the composite. Lower maximum working temperature, high coefficient of thermal expansion (dimensional instability), sensitivity to the radiation and moisture are the limitation of PMC's. As well as lower durability than the synthetic fiber, high moisture absorption, lower impact strength compared to synthetic fiber are some factor which restricts the application of natural fibers. The main objective of this review is to study the fabrication, characteristics, and performance of different natural reinforced polymer matrix composite for providing the fundamental concepts for further research and development in this area and to optimize the composites different applications. This review will be helpful to develop and understand the behaviour of different natural fibers for composite fabrication which are suitable for preparing the structural body and can be utilized in different applications.

2. POLYMER MATRIX COMPOSITE (PMC)

2.1 Polymer Matrix

The matrix is an important part of the composite which provides a protection against the adverse environment conditions. It also protects the surface of the fibres from mechanical degradation and transfers the load to the fibres. The most common used matrices in the natural fiber reinforcement composites are polymeric.

Polymer matrix composite (PMC) is the material which consists of a polymer (resin) matrix combined with a fibrous reinforcing dispersed phase. Polymer matrix composites are very popular due to their low cost and simple fabrication method. Both type of polymer, thermoplastic and thermosetting polymers are being used as matrices with natural fibres to prepare the natural reinforced polymer matrix composite [Holbery and Houston (2006)]. Thermosetting resins include polyesters, vinyl esters, epoxies, bismaleimides, and polyamides. Thermosetting polyesters are commonly used in fiber-reinforced plastics, and epoxies are the most trending matrix in advanced composites resins. Epoxies (polymers) have very good electrical insulating properties and are free from volatile material [Belaadi et.al. (2014), Borri et.al. (2013)]. Thermoplastic resins include some polyesters, poly-etherimide, polyamide imides, polyphenylene sulphide, polyether-etherketone (PEEK), and liquid crystal polymers. Basically matrix selection for the composite fabrication is limited by the temperature at which the reinforced (natural fibres) degraded. Most of the natural reinforcements used in the natural fibre composite are thermally unstable above 200˚ C temperature, but under some conditions, it is possible to be processed them at a higher level of temperature for a short period of time [Summerscales et. al. (2010)]. Due to the temperature limitation of natural reinforcement, only thermoplastics and thermosetting resins (which can be cured below this temperature limit) are usable as a matrix [Santos et. al. (2008)]. Thermoplastics are characterized of being repeatedly softened by the application of heat and hardened by the cooling. This property provides the potential for easy recycling. Polymers matrix can be used or bonded to nearly all the materials like natural fibers, wood, carbon, glass, and metal [Feng J and Guo Z. (2016)]. On another hand, a little or no shrinkage after curing is also an advantage of using the polymer as a matrix. Low maximum working temperature, high coefficient of thermal expansion (dimensional instability), sensitivity to the radiation and moisture are some issues which limit the application of polymer matrix in the composites. [Wang et al (2011)].

2.2 Reinforcement

While considering the classification in accordance with the form of dispersed or reinforcement phase, it is having continuous fiber-reinforced composite materials, sheet reinforced composite materials, short fiber/whisker reinforced composite materials, particle reinforced composite materials or particulate composite material and nanometer particle reinforced composite materials. Polymer matrix composites (PMC's) are made by a variety of short or continuous fibers bonded together by an organic polymer matrix. The continuous reinforcement of PMCs is responsible for their high strength and stiffness. The most important reinforcements used are glass, graphite, and aramid. Many of the particulate like silica aerogel, carbon black, CNT, calcium carbonate, mica, wollastonite, feldspar, and aluminum hydroxide are used for the preparation of PMC's. Inorganic particulates are also widely used as fillers in polymers and they not only reduces the cost of PMC but also changes other properties such as the modulus, hardness, strength, thermal properties, and fracture toughness. These inorganic particulate fillers do not increase the fracture toughness of composites as dramatically as rubber particulate. Inorganic particles are normally cleaned with alcohols to remove any surface contamination before they incorporate into polymers as fillers. Some Natural particulates are also extensively used as reinforcements into polymer matrices as an alternative to the commonly used synthetic fillers such as carbon, glass or aramid because of their low-density, good mechanical properties, abundant availability, and biodegradability. The PMC is designed so that the mechanical loads to which the structure is subjected in service are supported by the reinforcement and the matrix is used to bond the fibers together and to transfer loads between them Combination of strong and stiff reinforcement like carbon fibre and glass fiber, along with advances in polymer research to produce high-performance resins as matrix material has helped to meet the challenges for complex designs of modern aircraft. The large scale use of advanced polymer composites in current programs of development of military fighter aircraft, civil transport aircraft, helicopters, satellites, launch vehicles, and missiles is the most glowing example of the utilization of the potential of PMC's [Nayak (2014)].

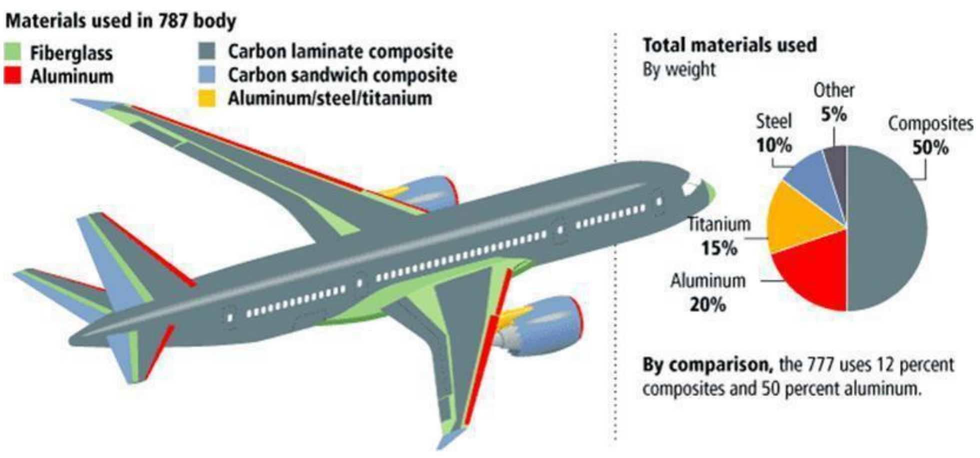

Fig. 1, Composite Materials in Aerospace Applications (Nayak, 2014

The increasing utilization of composite material can be seen in the structure of Boeing 787 (fig.1) in which approximate 50% of total weight of material used is composite. Composite materials are having properties like the relatively high compressive strength, good adaptability in fabricating thick composite shells, low weight and corrosion resistance. But, material characterization and failure evaluation of thick composite materials in compression is still an area of research. Glass reinforced plastics have wide application to naval & other vessels accompanied by application of conservative design safety factors due to limited durability data and to account for underwater shock loading, [Shivakumar et al.(2011)].

2.3 Natural Reinforcement

Basically, natural fibers or reinforcements are obtained from vegetable, animal, and mineral. Various parts of plants like seed, leaf, stem etc are the sources for obtaining natural fibers. These fibers provide a superior strength to a composite material when added to the polymer matrix. A great availability and easily fabrication have attracted the researchers to develop natural reinforced composites for the research. Basically, plants are used to produce two types of natural fibers/reinforcements. One is the primary fiber which is directly obtained from the plant's roots while the secondary fibers are the by-products from the utilization of the primary fiber. Primary fibers include Jute, hemp, kenaf, sisal, and cotton while secondary plants include wheat straw, bagasse, pineapple, agave, oil palm and coir [V. Mittal et.al (2016)]. Nano cellulose, which is a natural reinforcement, is often being considered as the next generation renewable reinforcement for the high-performance composite fabrication [Koon et. al. (2014)]. The performance of natural fiber reinforced polymer composite depends on several factors such as fiber chemical composition, fiber structure, dimension of fibers, microfibrillar angle of fiber, surface defects, physical and mechanical characteristics of the reinforcements while the natural fibers are combined with the polymer matrix [Codispoti et.al. (2015), Węcławski et.al. (2014)].

3. FABRICATION TECHNIQUES

Various common methods used for the fabrication of natural fiber composites are extrusion, injection moulding and compression moulding. Resin transfer moulding (RTM) is generally used for thermosetting polymer matrix composite. Angelov et.al. (2007) used Pultrusion process for flax /PP yarn composites and thermosetting polymer matrix composites. During fabrication processing, many factors which affect the properties of the composite are basically temperature, pressure, and speed of the fabrication process. As mentioned before, the natural fiber degrades if the temperature of processing is too high [Summerscales et. al. (2010)]. So the processing temperature should be lower than the temperature limit at which degradation of fiber will occur. In extrusion method, the matrix material usually in the form of small pellets, is heated and softened. After that, it is mixed with the reinforcement or fibers which are supplied by means of the rotating screws. The mixture is then compressed and forced out of the chamber at a steady rate through a die and filled into the mould. The high speed of the process may results the air inclusion and also the fibre breakage. On another hand low speeds may lead to poor mixing of the fiber and matrix and insufficient wetting of the fibres. Double screw extrusion system provides better dispersion of fibres and matrix and also the better mechanical characteristic comparatively to the single screw extruders [Malkapuram et.al. (2009)].

Injection molding process of composites can be used with both thermosetting and thermoplastic matrices, but this fabrication method is often used with the thermoplastic matrices. In injection molding, there are three main units - the feed hopper, heater barrel, and the ram. Polymers in granular or powder form are fed into the hopper. This raw material is heated to melt in the heater barrel. Once in hot liquid form, the ram forces this liquid into the tightly clamped mold. Where this liquid is allowed to solidify. More viscous molten plastics require higher pressures to force the plastic into the each corner of the mold. The plastic solidify as the metal mold conducts the heat away and then the final product is removed from the mold. Injection molding used for the production of complex shapes, some of which might be approximately impossible to produce economically by any other method. Injection molding is a low-cost process and a little scrap is produced in it, which can be re-used. Fiber alignment is more significant with higher fibre contents in the composite. Kim et. al. (2001) found that a variation of fibre orientation occurs across the section of the mould with shear flow along the walls of the mould due to the friction which results in the fiber alignment along the mould's wall. A higher stretch rate at the center of the mould results in more transverse alignment of the fibers along the flow direction. Ho et. al. (2012) investigated that residual stress in thermoplastic polymer matrix composites due to the pressure gradients, non-uniform temperature, polymer chain alignment and differences in fiber and polymer thermal expansion coefficients may reduce the fabricated composite strength. Injection moulding of the composites is generally limited to composites of less than 40 m% fibre content due to the viscosity requirement.

Compression molding is a closed mold process which generally is used for high-volume composite parts. In this fabrication process, the matched metal dies are mounted in a hydraulic molding press. The material charge is placed in the mold by manually or robotically. Then the heated mold halves are closed and a pressure is applied. The cycle time of compression can be from one to five minutes, depending on part size and thickness. Compression moulding is normally used for the thermoplastic matrix with loose chopped fibers or mats of the fibers, but it can also be used for the thermosetting polymer. In this method, reinforcement is normally stacked alternately with the thermoplastic matrix before pressure and heat are applied. To make it sure that the matrix is filled properly into the space between fibres, the viscosity of the matrix during compression and heating needs to be carefully controlled [Ho et. al. (2012)]. Bodros et. al. (2007) noticed that film stacking limits the natural fibre degradation as it involves only one temperature cycle. Alternatively, to film stacking, sheet moulding compounds can be used in compression moulding [van et. al. (2001)]. Temperature control has an important role in the process. A reduction of fibre strength has been noticed at temperatures as low as 150˚ C and at 200˚ C, with strength reducing by 10% in a time period of 10 minutes [Herrmann et. al. (1998)]. There should be a compromise between obtaining good wetting of fibers and avoiding the fibers degradation due to a higher temperature which leads to an optimum temperature limit for processing a particular composite material.

Resin transfer molding (RTM) is used to produces large, complex items such as aircraft parts, automotive components, bath and shower enclosures, and cabinets. In RTM process, a set of mold halves is clamped together after loaded with a reinforcement material. After that, the Resin is pumped or gravity fed into the mold infusing the reinforcement material. Once the mold is filled with resin it is left for the curing process. The main variables parameters with RTM process are temperature, pressure, resin viscosity, and mould configuration [Ho et. al. (2012)]. The main advantages of this fabrication method compared with other processes are lower temperature requirements and relax from thermo-mechanical stresses. Good composite strength can be achieved with this process which is suitable for low production cost and running [Pickering (2008)].

4. WATER ABSORPTION

The most common problem associated with natural reinforcement in PMC is the moisture absorption. The moisture absorption content increases with the increment of reinforcement percentage, temperature. Moisture content is also affected by fiber treatment as well as by the application of coupling agent. Moisture or water absorption generally reduces the mechanical performance of the composite materials But the impact energy is the mechanical property which commonly seen to increases with the moisture absorption in the natural reinforced composites.

Dheenadhayal (2013) analysed water absorption properties of hybrid natural fiber reinforced polymer composite material and found that 40 vol. % of sisal and bagasse hybrid natural fiber reinforced polymer composite composition absorbed a 4.68 % amount of water content. Alamri and Low (2012) have investigated the effect of fiber weight percentage on the water absorption capacity of the recycled cellulose fiber reinforced epoxy matrix composite. The composite showed higher water absorption with the increasing the fiber contents and the maximum value of water absorption was achieved at 46 wt % of fiber contents. They also noticed that the water absorption of composites has decreased by the addition of nano-silicon carbide particles, which improve the interfacial adhesion of fiber and polymer in the composite. An improvement in the adhesion at the interface of fiber and polymer in the cellulose fiber/epoxy composites has been noticed due to the addition of nano-silicon carbide particles in the composite. These nano-silicon carbide particles decreased the water absorption of composites, which results in improvement of interfacial adhesion [Alamri and Low (2012)]. Water diffusivity of the weave flax fiber reinforced composite was analyzed by Newman (2009). While comparing, the water absorbed by flax epoxy composites seems to be higher as compared to the E-glass fabric reinforced polyester composite. Another observation is that the weave flax reinforced composite becomes swollen after the absorption of water and these fibers shrinks faster than the matrix while drying the composite. The water absorption properties of the sisal fiber reinforced epoxy composites got affected with the addition of nano-clay in it. It is found that 5 wt % nano-clay has lower water absorption characteristics [Mohan and Kanny,(2011)]. The tensile strength of the polycarbonate resin decreases as the water absorption time increases, while the tensile modulus of polycarbonate does not change [Tanaka et al. (2010)].

Mylsamy and Rajendran (2011) studied the effect of NaOH treatment of the agave reinforced epoxy composites and found that the sodium hydroxide treated fiber composite shows the low value of water absorption as compared to the untreated fiber reinforced composites. Hossai (2014) et al. has studied the effect of chemical treatment on physical properties of wood saw dust particles reinforced polymer matrix composite. The strength of wood particles reinforced polymer matrix composite has increased after the chemical treatment (with 10% NaOH) of wood saw dust. Due to the difficulty of uniform mixing and improper distribution of particulate inside the matrix, these saw dust reinforcement has decreased the strength of PMC as compared to pure polymer. The chemical treatment of the particulate has also increased the water absorption behaviour of PMC. This behaviour is also increased with a period of water absorption and particulate content.

5. THERMAL CHARACTERISTICS

All the polymers generally have very low thermal conductivity, which means that the polymer matrix composite is good insulators of heat. But on another hand the natural fibers or reinforcements degraded at a higher temperature. So the thermal characteristics of the natural reinforced polymer matrix composite are an important field of research.

The thermal conductivity of the composite is an anisotropic property same as Young's modulus [Hashim et. al. (2011)]. Sherely et al. (2008) estimated the thermal conductivity and thermal diffusivity of the banana fiber reinforced polypropylene composite and found that the thermal conductivity and thermal diffusivity of the composite decreases with increment in the fiber loading. The thermal conductivity and diffusivity of the sisal reinforced polyethylene, glass reinforced polyethylene and sisal-glass hybrid reinforced polyethylene was analysed by Kalaprasad et. al. (2000) from a low to high-temperature range i.e. 120±350 K. It was found that the thermal conductivity increases with temperature and stop increasing afterward. Talebi et al. (2015) had investigated and compared the thermal insulating properties of nonwoven fabric and silica aerogel/nonwoven fabric composite after determining the thermal diffusivity and thermal conductivity of the composites. The presence of silica aerogel in the matrix of nonwoven fabric has decreased the thermal diffusivity of the composite compared to the neat nonwoven fabric. The thermal diffusivity and thermal conductivity of the silica aerogel reinforced composite decreases with a decrement in the silica aerogel content. Martina et al. (2016) had prepared the composites of three bulk densities made from each mixture of hemp fibers and cellulose fibers (60:40), cellulose fibers 100%, cellulose fibers and straw (30:70) and straw 100%. The thermal properties in different conditions are tested and the best thermal insulation property is achieved by the mixture based on 100% cellulosic fibers. This mixture is least sensitive to relative humidity in terms of its thermal insulating properties. On the other hand, the greatest deterioration in thermal insulating properties occurred in the samples with higher content of straw fibers. Mounika et. al. (2012) found that the thermal conductivity of the bamboo fiber reinforced composite decreased with the increment in fiber content and a just opposite trend was noticed with respect to the temperature. Fiber orientation in the composite had also a significant effect on the thermal conductivity of the composite This bamboo fiber reinforced composite can be utilized in building and the automotive industry to save energy by reducing heat transfer rate. The effect of clay concentration on the thermal behaviour of recycled cellulose fiber/epoxy composites has been investigated. The addition of nano-clay in the composite increased the thermal stability of the composite and also hikes the char residue over the neat epoxy [Alamri et al. (2012)].

Alkali treatment of the reinforcement used in the composite also affects the thermal properties of the composite fabricated. Kumar SMS et. al. (2014) studied the thermal characteristics of the untreated, as well as the alkali, treated coconut sheath reinforced composites. This study reported that the composites fabricated by alkali treated coconut sheath fiber proved better in thermal stability as compared to composite fabricated from the untreated coconut sheath reinforcement. Also, Liu et al. (2014) investigated the effect of chemical treatment (alkali treatment) and mercerization on the thermal characteristics of the abaca fiber reinforced epoxy matrix composites. In the investigation, it was found that both the treatments have a positive effect on the bonding between the fiber and polymer in the composite fabricated. The treated fiber composite has better thermal conductivity as well as lesser void content comparatively to the untreated fiber reinforced composite. The transverse thermal conductivity of the abaca fiber reinforced epoxy matrix composites was enhanced due to the chemical treatments of the fiber, which has changed the cell wall structure of the composite.

6. MECHANICAL PROPERTIES

Interfacial connection (bonding) between the reinforcement and matrix has a vital role in determining the mechanical properties of composite fabricated. The stress is transferred between matrix and fibers across the interface so a better interfacial bonding is required for achieving and optimum strength. Natural fiber based composites generally have limited interfacial interaction between the fibers and matrix. The reason behind this poor interaction is that the natural reinforcements are hydrophilic and the polymer matrix has a hydrophobic nature. This poor interfacial limits the mechanical performance as well as low moisture resistance which affects the long term properties of the composite. An insufficient fiber wetting can also result in the interfacial defects which may enhance the stress concentration [Chen et. al. (2006)]. Fibers wet-ability greatly affect the toughness, tensile and flexural strength of composites Interfacial bonding of fibers and matrix can be obtained by mechanisms of mechanical interlocking, electrostatic bonding, chemical bonding and interdiffusion bonding [Matthews et. al. (1999)]. Mechanical interlocking comes into the picture when the surface of the fibers is rough enough. Mechanical interlocking increases the interfacial shear strength but has a lesser effect on the transverse tensile strength of the composite. Electrostatic interfacial bonding only has significant influence in the case of metallic interfaces. Chemical bonding occurs when there are chemical groups are present on the surface of the fibers and in the matrix. These chemical groups react together and form bonds. Chemical bonding can also be obtained by using a coupling agent which acts as a connecting bridge between the surface and matrix of the fiber. Interdiffusion bonding is related to the atoms and molecules of the fibre and matrix. This type of bonding occurs when atoms and molecules of the fiber and matrix interact with each other at the interface. It is also possible that more than one type of bonding can be present on the fiber and matrix interface at the same time [Beckermann (2007)]. Agunsoye and Aigbodion (2013) have prepared bagasse filled recycled polyethylene bio-composites by the compounding and compressive molding method. The surface morphology and the mechanical properties of the composites on examination show that the uniform distribution of the bagasse particulate in polymer composites is the major factor, which improves the mechanical properties. The best properties of the composite are obtained in the ranges of 30 wt% bagasse particle. Also, Liu et al. (2014) investigated the effect of chemical treatment (alkali treatment) and mercerization on the thermal characteristics of the abaca fiber reinforced epoxy matrix composites. In the investigation, it was found that both the treatments have a positive effect on the bonding between the fiber and polymer in the composite fabricated. To improve the instantaneous mechanical performance, chemical treatment of the fiber surface has been found to improve the longer term mechanical performance of natural fiber composites in wet and humid conditions [Singh et. al. (1996)].

6.1 Hardness and Toughness

Dheenadhayal (2013) studied the mechanical properties of hybrid natural fiber reinforced polymer composite material and found that 40 % (volume) of sisal and bagasse hybrid natural fiber reinforced polymer composite attain maximum hardness value. Sivasaravanan et al. (2014) prepared epoxy/clay nanocomposites by hand layup techniques and performed mechanical tests (tensile test, impact test, and hardness test). Various mechanical tests and microstructural investigation were carried out. The impact test results (toughness) of nanocomposite materials improved with the addition of nano clay in an epoxy matrix. It was found that the addition of 5 wt% of nano clay shows very good results compared to another percentage of nano clay. If the percentage of nano-clay is more than 5 (wt %) in the composite material, it becomes brittle material and also very hard to prepare composite material. Therefore the nano-clay contents should be kept within 5 (wt %) in order to get good mechanical properties. Paul et al. (2003) studied whether the natural fibres can replace glass in fibre reinforced plastics or not. The mechanical properties of sisal, hemp, coir, kenaf and jute reinforced polypropylene composites, while studied, shows that the tensile strength and modulus increase with increasing fibre volume fraction. The coir reinforced PMC shows the lowest mechanical properties, whereas the hemp PMC shows the highest but the impact strength of coir composites is higher than jute and kenaf composites. The mechanical properties of these natural fibres PMC, when compared with the corresponding properties of glass mat polypropylene composites, shows that specific properties of the natural fibre composites in some cases are better than those of glass. So it can be concluded that the natural fibre can be used to replace glass in PMC for many applications. Mechanical and fracture performance of carbon fibre reinforced composites with nanoparticle modified matrices is studied by CaroIan et al. (2016). The toughness improvements can be seen compared to the values of the unmodified epoxy polymer (i.e. without any toughening particles present). The toughness of an epoxy polymer or CFRP laminate containing silica nanoparticles and core-shell rubber (CSR) nanoparticles and both, decreases at the lower test temperature (-80°C) when compared to the toughness at room temperature. The toughness value of the CFRP laminates, with respect to the bulk epoxy polymer, can be further enhanced by additional fibre-based toughening mechanisms, i.e. fiber bridging, fibre debonding and fibre pull-out. On the addition of 5% w/w lignin in the hemp reinforced epoxy composite, it improves the impact strength of the composite up to 145 % [Benjamin et al. (2011)]. Impact strength is basically can be considered t one of the weaknesses of natural fiber reinforced composite [Faruk et. al. (2014)].

The influence of the clay content on the mechanical behaviour of the recycled cellulose fiber reinforced epoxy composites has been investigated and it is noticed that the mechanical strength (fracture toughness and fracture impact) of the composite improves by 30 to 40 % while adding 1 wt% clay in composite and the maximum impact strength is obtained corresponding to the 46 wt % of the cellulose fiber loading in the composite [Alamri et al.[22] (2012)]. Also the water absorption of the same composite has not any significant effect on the impact strength of the composite [Alamri et al.[23] (2012]. Enzyme treatment has been found beneficial for the improvement of impact properties as an improvement of 25 % has been noticed in the impact strength of abaca/PP composites by [Bledzki et. al. (2007)]. The impact strength of epoxy resin has been seen to reduce with the addition of fiber up to 25 m % fiber, but then increase to give an overall improvement in impact strength of 40% with a fiber content of 40 m% [Mutasher et. al. (2011)].

6.2 Tensile Strength

The tensile characteristics of different natural reinforced composites (sisal, hemp, coir, kenaf and jute reinforced composites) have been studied, and it was found that among all these composites, hemp reinforced composite was having the highest mechanical properties whereas the coir reinforced composite exhibited the lowest [Sreenivasan et. al. (2011)]

Dheenadhayal (2013) analysed the mechanical properties of hybrid natural fiber reinforced polymer composite material and found that 60 % (vol.) of sisal and sugarcane bagasse hybrid natural fiber reinforced polymer composite attain the maximum tensile strength of value a 29.49 N/mm^2. The influence of lignin on the mechanical properties of the hemp/epoxy composites has been investigated by Benjamin et al. (2011). Modulus of elasticity of the composite found to increase while raising the lignin percentage up to 2.5% w/w. Further increment in the concentration of lignin, it started dwindling, which causes the poor mixing of reinforcement and matrix due to the high viscosity. The effect of piassava fiber loading in the piassava fiber reinforced epoxy matrix composite has been investigated by Nascimento et al. (2012) and it was found that 41 % improvement in the tensile strength of the composite takes place with the increment of fiber loading.

Romli et al. (2012) also analyzed the influences of the fiber loading, curing period of composite and the compression load on the tensile properties of the coir reinforced epoxy matrix composite. In the analysis, they reported that the tensile properties of the composite are mainly affected by the fiber loading in the composite and the curing time of it, while a compression loading has no adverse effect on it. Tensile characteristics of the sisal reinforced epoxy composite with nano clay particulate got slightly reduced after the water absorption of the composites. On other hand, tensile characteristics got enhanced appreciably with the nano clay particulate filled composites [Mohan and Kanny (2011)].

The effect of moisture content or absorption on the tensile properties of natural fibers including jute, abaca, kenaf, flax sisal, hemp, and coir has been studied by Symington et al. (2009) and they concluded that the jute fiber exhibited better mechanical properties than other fibers.

Physical treatment and chemical treatment can improve the wettability of the fibre and thus improve the interfacial strength. Agunsoye and Aigbodion (2013) have prepared bagasse filled recycled polyethylene bio-composites by the compounding and compressive molding method. The surface morphology and the mechanical properties of the composites on examination show that the uniform distribution of the bagasse particulate in polymer composites is the major factor, which improves the mechanical properties. The bagasse particles have improved the rigidity and the hardness values of the composites. The tensile and bending strengths of the composite have increased as the percentage of bagasse particulate increase up to 20 wt% (uncarbonized) and 30 wt% (carbonized), as well as the impact energy and fracture toughness decreases with the increment in weight percentage of bagasse particles. The best properties of the composite are obtained in the ranges of 30 wt% bagasse particle. Enzyme treatment has been found beneficial for the improvement of tensile strength as an improvement of 45 % has been noticed in the tensile strength of abaca/PP composites by [Bledzki et. al. (2010)].

6.3 Flexural Strength

Benjamin et al. (2011) found that the flexural modulus of the hemp reinforced epoxy composite increases on raising the concentration of lignin up to 2.5% w/w, however above that, it started dwindling, which can be attributed to poor mixing of reinforcement and matrix due to the high viscosity. Mishra and Biswas (2013) investigated the influence of the weight percentage of the reinforcement on the mechanical strength of the jute fiber reinforced epoxy composites. It was found that the void content are reduced in the composite by the adding the jute fiber up to a certain limit. The jute fiber reinforced epoxy composites exhibits superior flexural and inter-laminar shear strength at 48 wt% jute fiber content in the composite because at this level composite has less void content. Nascimento et al. (2012) investigated the influence of fiber percentage on the mechanical properties of the piassava fiber reinforced epoxy matrix composites. An increment in the fiber loading in the epoxy resin will improve flexural characteristics of the composite up to 30 %. While investigating the effect of environmental condition, the addition of montmorillonite and alkali treatment of the reinforcement on the flexural properties of the fique fiber reinforced epoxy composites, It was found that the composite with the treated fiber and containing montmorillonite have 34 to 40 % more flexural properties. The flexural properties of fique fiber reinforced composite was also better than the wood [Hoyos and Vazquez (2012)].

The NaOH treatment (alkali treatment) is not suitable for modification of tenax leaf fibers for improving the flexural characteristics of composites in which they are used as reinforcement [Newman et al. (2007)]. The increment in the time period of alkali treatment had no effect on the mass loss of tenax fiber, on another hand increment in the concentration of treatment provides a significant mass loss due to the removal of impurity and other surface contents. Enzyme treatment has been found beneficial for the improvement of flexural strength as an improvement of 35 % has been noticed in the flexural strength of abaca/PP composites by [Bledzki et. al. (2010)]. Gassan and Gutowski have used corona plasma and UV for the treatment of jute fibers. Both the treatment has been found beneficial for increasing the polarity of fibers but decrease the fiber strength which leads to reduce the composite strength with corona treatment. An improvement of 30% in flexural strength of epoxy matrix composites with UV treatment is observed [Gassan et. al. (2000)]. Heat treatment has also been observed to give good improvement of sisal fibre strength up to 37%, as heat treatment removes the aromatic impurities. An increment of 27 % in the flexural strength has been noticed due to the heat treatment [Rong et. al. (2001)]. Le and Newman (2007) found that the flexural modulus was almost similar for flax reinforced epoxy composite to epoxy reinforced with glass CSM at the same weight fraction but while considering the flexural strength, it was found only about two-thirds that for the GFRPs [Le et. al. (2007)].

6.4 Wear Performance

Natural reinforcements have a good potential to enhance the wear characteristic of the polymer composites. Pramendra et. al. (2012) investigated the wear performance of natural fibre reinforced polypropylene composites. The influence of nettle, grewia option and sisal fibres in the polypropylene matrix composite is studied and it was noticed that incorporation of this natural reinforcement into the polypropylene has improved the wear resistance of the neat polymer.

Wear behaviour of epoxy hybrid particulate composites (hybrid PMC) is studied by Srinivas and Bhagyashekar (2014). Under the tribological behaviour of epoxy composites containing three different particulate fillers (i.e. Gr, SiC, and Gr-SiC), the wear test results show that the hybrid composite with Gr-SiC particulate is having higher wear resistance and lower specific wear when compared with that of Gr particulate composite and SiC particulate composite. The improvement in this wear resistance for the hybrid composite containing 5% SiC - 35% Gr is 85% when compared with virgin epoxy and 25% and 36% over the composite containing 40% Gr and 40% SiC respectively. The composites having 5% Gr and 35% SiC exhibits highest wear resistance. The wear characteristics of the sisal reinforced epoxy composite with nano clay particulate got slightly reduced after the water absorption of the composites. On another hand, wear characteristics got enhanced appreciably with the nano-clay particulate filled composites [Mohan and Kanny (2011)]. While examined the influence of fiber orientation on the wear and fractional properties of the bamboo fiber reinforced epoxy matrix composites, it was found that anti-parallel orientation of the bamboo fibers in the composite contributes in good adhesive wear characteristics (improved by about 60%) than any other orientation of the fibers in the composite. The frictional performance of the composite was also better for an anti-parallel orientation of the bamboo fibers in the composite at low sliding velocity [Nirmal et al. (2012)]. The effect of reinforcement particle size on the wear and frictional performance of a betelnut fiber (treated) composite has been studied by Yousif et al. (2010). They have reported that the frictional coefficient of the coarse particle-fiber reinforced composite has a large value. On another hand, it was found that the abrasive wear of the composite mainly depends on the particle size of reinforcement and sliding velocity.

7. SUMMARY

Polymer matrix composite (PMC) is the material which consists of a polymer matrix combined with a reinforcing dispersed phase. Thermosetting and thermoplastic resin are two basic polymers used as the matrix phase in PMC’s. Over the past decade, the use of natural fibers/reinforcements as a substitute for the synthetic fiber (carbon and glass) in the development of polymer matrix composites has attracted the attention of researchers. The properties of natural fibers like huge availability, low density, low cost, renewability, and biodegradability make them suitable used with a polymer to produce natural reinforced polymer matrix composite materials [Premalal et. al. (2002)]. Due to the above-mentioned advantages of natural reinforced composites, there is a strong driving force to use them for replacing GFRPs. The stiffness (tensile modulus) values for the natural fibers composite approach the upper values obtained for GFRPs, although strength falls well short. Density provides a more favourable comparison as a higher specific stiffness can be achieved with natural fiber composite than GFRPs. But on another hand highest specific strengths are obtained with GRRPs in comparison with natural fiber composite. Various natural reinforcements such as silica aerogel, banana fiber, bamboo fiber and hemp fiber in their treated or untreated form can be utilized for providing better thermal characteristic to the polymer matrix composites. The tensile and flexural performance of natural fiber reinforced polymer matrix composites are mainly depends on the fiber loading and moisture absorption which affects the interfacial bonding of fibers with the matrix in the composites. The most common problem associated with natural reinforcement in PMC is the moisture absorption. Impact strength can also be considered to one of the weaknesses of natural fiber reinforced composite material [Faruk et. al. (2014)]. Natural fiber reinforced composites are having an advantage over the metals where excellent corrosion resistance is required.

8. ENVIRONMENTAL DEGRADATION AND SPECIAL PROBLEM IN WORKING WITH PMC’s AND NATURAL FIBERS

Polyethylene (PE) and polypropylene (PP) based PMC materials are being extensively used for commercial and household purposes in today’s life. These polymer based plastics and composite are resistive to biodegradation. Thus their increasing accumulation in the environment is becoming an ecological threat to the world. Consequently, over the last couple of decades, many studies on the biodegradation of plastics have been carried out in order to overcome the environmental problems associated with these synthetic polymer wastes. Cintia et al. (2015) have done a comparative study of agro-industrial wastes for their use in polymer matrix composites. Low density, easy processing, low cost, abundance and biodegradability of natural fibers make them ideal for use as organic particulate in polymer matrices. The properties of these PMC’s depend on the composition of the fiber, the interfacial adhesion between reinforcement and matrix, the size of the particulate and aggregate weight percent. The suitability of wastes from olive and wine industries (olive wet husk, olive pits, and grape stalks) through a comparative study of the resulting particles for subsequent use in polymer matrix composites has studied. The olive wet husk shows a wider particle size distribution, olive pits shows a more narrow distribution and better stability against thermal degradation and the grape stalks exhibits the greater amount of surface groups and a more fibrous structure. Degradation behaviour of natural fiber reinforced polymer matrix composites has been studied by Fakhrul and Islam (2013). The biodegradability of PP is observed to improve by blending it with small additions (5%) of wood sawdust and wheat flour. These PMC’s while exposed to various environmental conditions (exposure to the open atmosphere, moist soil, and water and brine solution) for a period of 15 weeks, the signs of crazing and discoloration are observed. The extent of this biodegradability of the composites is also observed by a change in bonding nature by FTIR spectroscopy. The addition of these both sawdust and wheat flour considerably improved the biodegradability of PP. The most pronounced biodegradation occurs when samples are exposed to brine solution and buried under the moist soil.

Now a day’s polymer matrix composites are being increasingly used in applications where they are exposed for long durations to hostile environments such as elevated temperatures, moisture, oils, and solvents. Although polymers based plastics and composites are resistive to biodegradation, the exposure into these types of the environment may lead to the degradation of the natural reinforcement used with the polymer matrix, which affects the lifetime of structures made from natural reinforced PMC's. In all the aerospace applications of polymer matrix composites such as engine supports, reusable launch vehicle parts, thrust-vectoring flaps, and the thermal insulation of rocket motors, the materials have to face a hostile environment such as higher temperature. These all demands have led to efforts to develop lightweight, higher-strength, higher-modulus materials that have long-term durability.

Delamination is the most important mode of damage propagation in PMCs with laminar structures. The poorly bonded interfacial region between the fiber and matrix has a critical influence on PMC behaviour. Recycling and disposal of most PMC materials is a major field of concern. Thermosetting matrices, after they have been cured, have no apparent scrap value. Although attempts have been made to grind them up and use them as fillers this has not proven to be practical economically. By contrast, the scrap of thermoplastic matrices can be recycled. The incineration of the polymer is generally avoided because it can generate toxic smoke. The principal problem associated with PMC disposal arises with uncured PMCs as wet lay-ups and prepregs are still chemically active and can cause both health and safety problems. If we used it in a landfill, the active chemicals may leach out and cause contamination of the soil and water. A more serious problem is that the catalyzed resins may go on to cure and generate an exotherm that causes spontaneous combustion or self-ignition. As previously mentioned, the natural reinforcement has hydrophilic nature so the moisture absorption is one of the main disadvantages with the natural fiber composite. Moisture absorption increases with the increased fibre content and temperature. It reduces the mechanical performance of natural fiber composites with the exception of impact energy which is generally increasing. Baghaei et. al. (2014) found that non-woven hemp fibre PLA composites absorb more moisture than the aligned fibre composites; this was due to the increased porosity because of the increased complexity of the matrix flow path during processing. Alkali treatment of the fibers helps in increasing the resistance to moisture.

APPLICATIONS

Over the last three decades, an increasing trend of utilization of natural fiber reinforced polymer matrix composite have been seen in automobiles door panels, package trays, hat racks, instruments panels, internal engine covers, sun visors, boot liners, oil/air filters as well as seat backs and exterior under-floor paneling. Today all of the main automobiles manufacturers are using natural reinforced polymer composites and their use is this area expected to increase in the future [Faruk et. al. (2014)]. Composite board has been developed in India to use as an alternative to the medium density fiber-board used in rail coaches [Pickering (2008)]. The aircraft industry also utilizing the natural fiber reinforced composite for the interior panel design and seats of aircraft. [Ho et. al. (2012)]. Natural reinforced composite have also been used in the various applications such as in toys, funeral articles, packaging, marine railings and cases for electronic devices such as laptops and mobile phones as a replacement for synthetic fiber. Equipment of sports are now embracing the environmentally friendly materials. Various companies are now producing surfboards incorporating natural fiber composite material. Hernandez et. al. (2013) has supported the production of surfboard fins with natural fiber through RTM process, which provides a good provision for mechanical performance and economic viability. Recently RTM process has been used for the production of turbine blades with flax reinforced polyester composite by replacing the material which is reinforced with glass fiber [Shah et. al. (2013)]. Natural fiber composites have also being used for top-plates of string musical instruments [Phillips and Lessard (2012)]. Cellu-Comp Ltd is producing the fishing rods with the nano-cellulose (extracted from the vegetable root) natural composite [Annabelle (2014)]. While talking about construction natural reinforced composite (wood fiber reinforced PP or PE etc) are being used extensively in decking, floor lamination, door, and windows. [Youssef et. al. (2012)]. Natural fiber composites have better mechanical properties for replacing the wooden laminates in insulating structural panels [Uddin et. al. (2011)]. The possibility of using natural fibre composite sheet piles by evaluating the flexural behavior of extruded hollow cross-section wood-plastic composites with 50 m% wood flour has been investigated [Alvarez et. al. (2009)]. Reinforcing the cement by natural fibers for building materials has also been assessed [Faruk et. al. (2014)]. Natural reinforced composites have a great potential across range applications including automotive, aerospace, construction and the sports industries.

CONCLUSIONS

Many important types of research have been done over the last three decades in the area of natural fiber/reinforcement polymer matrix composites. This paper has presented a review of the various researchers that has focussed on the fabrication techniques of natural fiber polymer matrix composite as well as improving tensile strength, flexural strength, and impact strength. An enhancement in the toughness of PMC can be noticed by adding some toughening particles (nanoparticles) of nano clay, silica, and core-shell rubber. The fracture performance of natural reinforced polymer matrix composite becomes better by the cleaning of particulates used. Wear properties of the natural fiber polymer composite has also been analysed. PMC contains good wear properties as they provide oil-less lubrication in their tribological application. The major concern in the use of PMC's is that in an aggressive chemical environment polymer molecules break (chain scission), cross-link, or suffer substitution reactions. This review has also focused on the problems associated with the utilization of the natural reinforcements in PMC's. The effect of processing temperature limit, the effect of water or moisture absorption and other weathering condition on the properties of the composite has also been discussed. Material characterization and failure evaluation of thick natural reinforced polymer composite materials in compression is still an area of research. Low maximum working temperature, high coefficient of thermal expansion (dimensional instability), sensitivity to the radiation and moisture are some issues which limit the application of polymer matrix composite. The thermal insulating properties of PMC are found to be improved by involving the silica aerogel and some other natural particulate (hemp and cellulose). It has been analyse throughout the review whether the natural reinforced polymer composite can be used as an alternative of other synthetic reinforcement like carbon and glass fibers. A lower value of density enables the natural fibers to show the better comparison for specific properties. Applications of natural fiber composite have extended dramatically such as in load bearing, outdoor applications such as automotive and aircraft interior, sports equipment, and marine structures. Further research is still going on to extend their application areas as well as improvement in its moisture resistance and fire resistance. The development of natural reinforced composite is on the way rapidly and there is a very positive future for their application.

REFERENCES

1) Agunsoye J.O., Aigbodion V.S., Bagasse filled recycled polyethylene bio-composites: Morphological and mechanical properties study, Results in Physics, Elsevier, (2013).
2) Alamri H, Low IM. Alothman Z. Mechanical, thermal and microstructural characteristics of cellulose fiber reinforced epoxy/organoclay nanocomposites. Compos Part B Eng; 43: 2762–2771 (2012).
3) Alamri H, Low IM. Effect of water absorption on the mechanical properties of nano-silicon carbide filled recycled cellulose fiber reinforced epoxy eco-nanocomposites. Polym Test; 31: 810–818 (2012).
4) Alvarez-Valencia D, Dagher HJ, Lopez-Anido RA, Davids WG, Gardner DJ, Center AC. Behavior of natural-fiber/thermoplastic sheet piling. Presented at ACMA-composites and polycon conference, 15–17 January 2009, Tampa, Florida, USA; (2009).
5) Angelov I, Wiedmer S, Evstatiev M, Friedrich K, Mennig G. Pultrusion of a flax/ polypropylene yarn. Composites Part A;38(5):1431–8 (2007).
6) Arcos Paco de, Portugal, Conference on Fracture, Procedia Structural Integrity vol. 1 074-081, (2016).
7) Arrakhiz FZ, Malha M, Bouhfid R, Benmoussa K, Qaiss A. Tensile, flexural and torsional properties of chemically treated alfa, coir and bagasse reinforced polypropylene. Composites: Part B; 47:35– 41(2013).
8) Baghaei B, Skrifvars M, Salehi M, Bashir T, Rissanen M, Nousiainen P. Novel aligned hemp fibre reinforcement for structural biocomposites: porosity, water absorption, mechanical performances and viscoelastic behaviour. Composites Part A;61:1–12 (2014).
9) Baptista Ricardo, Mendao Ana, Guedes Mafalda and Marat-Mendes Rosa, An experimental study on mechanical properties of epoxy-matrix composites containing graphite filler, XV Portuguese. Procedia Structural Integrity vol. 1 074–081, (2016).
10) Beckermann G. Performance of hemp-fibre reinforced polypropylene composite materials. Ph.D. thesis. Hamilton, New Zealand: University of Waikato; (2007).
11) Belaadi A, Bezazi A, Bourchak M, et al. Thermochemical and statistical mechanical properties of natural sisal fibres. Compos Part B; 67: 481–489(2014).
12) Benjamin MW, Stuart RC, Maggs S, et al. Use of lignin as a compatibiliser in hemp/epoxy composites. Compos Sci and Technol; 71: 1804–1810 (2011).
13) Bledzki AK, Mamun AA, Jaszkiewicz A, Erdmann K. Polypropylene composites with enzyme modified abaca fibre. Compos Sci Technol;70(5):854–60 (2010).
14) Bledzki AK, Mamun AA, Jaszkiewicz A, Erdmann K. Polypropylene composites with enzyme modified abaca fibre. Compos Sci Technol;70(5):854–60 (2010).
15) Bodros E, Pillin I, Montrelay N, Baley C. Could biopolymers reinforced by randomly scattered flax fibre be used in structural applications? Compos Sci Technol;67(3):462 70 (2007).
16) Boopalan M, Niranjanaa M, Umapathy MJ. Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites. Composites Part B; 51: 54-57(2013).
17) Borri A, Corradi M, Speranzini E, et al. Reinforcement of wood with natural fibers. Compos Part B, 53: 1–8(2013).
18) C. Baillie, Green Composites: Polymer composites and the environment. Woodhead Publishing. (2004).
19) CaroIan DecIan, Kinlocha A.J., Ivankovic A., Sprenger S. and Taylor A.C., Mechanical and fracture performance of carbon fibre reinforced composites with nanoparticle modified matrices 21st European Conference on Fracture, ECF21, Catania, Italy, Procedia Structural Integrity vol. 2 096– 103, (2016).
20) Annabelle Ewing, Cellucomp Sustainable Materials. Cellucomp's first bio-refinery plant opened, MSP; (2014).
21) Chen P, Lu C, Yu Q, Gao Y, Li J, Li X. Influence of fiber wettability on the interfacial adhesion of continuous fiber-reinforced PPESK composite. J Appl Polym Sci;102(3):2544–51 (2006).
22) Codispoti R, Oliveira DV, Olivito RS, et al. Mechanical performance of natural fiber reinforced composites for the strengthening of masonry. Compos Part B; 77: 74–83(2015).
23) Dheenadhayal S., Analysis of Hybrid Natural Fiber Reinforced Polymer Composite Material, International Journal of Research in Mechanical Engineering Volume 1, Issue 2, pp. 45-50, © IASTER (2013).
24) Dos Santos PA, Giriolli JC, Amarasekera J, Moraes G. Natural fibers plastic composites for automotive applications. In: 8th Annual automotive composites conference and Exhibition (ACCE 2008). Troy, MI: SPE Automotive & Composites Division; p. 492–500 (2008).
25) Fakhrul Taking and M. A. Islam, Degradation behaviour of natural fiber reinforced polymer matrix composites, 5th BSME International Conference on Thermal Engineering. Procedia Engineering vol. 56 795 – 800, (2013).
26) Faruk O, Bledzki AK, Fink HP, Sain M. Progress report on natural fiber reinforced composites. Macromol Mater Eng;299(1):9–26 (2014).
27) Faruk O, Bledzki AK, Fink HP, Sain M. Progress report on natural fiber reinforced composites. Macromol Mater Eng;299(1):9–26 (2014).
28) Feng J, Guo Z. Temperature-frequency-dependent mechanical properties model of epoxy resin and its composites. Compos Part B; 85: 161–169(2016).
29) Feret Victor, Ghiasi Hossein & Hubert Pascal, Effect of Fibre Volume Fraction on Mixed-Mode Fracture of a Fabric Carbon/Epoxy Composite, Springer, Media B.V. (2012)

30) Fiore V, Di Bella G, Valenza A. The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites. Compos Part B,;68: 14–21 (2015).
31) Fiore V, Scalici T, Nicoletti F, et al. A new eco-friendly chemical treatment of natural fibres: Effect of sodium bicarbonate on properties of sisal fibre and its epoxy composites Compos Part B; 85: 150– 160(2016).
32) Francucci G, Rodriguez ES, Vazquez A. Experimental study of the compaction response of jute fabrics in liquid composite molding processes. J Compos Mater;46(2):155–67 (2012).
33) Gassan J, Gutowski VS. Effects of corona discharge and UV treatment on the properties of jute fibre epoxy composites. Compos Sci Technol;60 (15):2857–63 (2000).
34) Gauda TM, Naidu ACB, Rajput C. Some mechanical properties of untreated jute fabricreinforced polyester composites. Compos Part A; 30: 277–284(1999).
35) Glaris P, Coulon JF, Dorget M. Fluorinated epoxy resin as a low adhesive mould for the composite material. Compos Part B; 63: 94–100 (2014).
36) Hashim Rokiah, Wan Noor Aidawati Wan Nadhari, Sulaiman Othman,kawamura Fumio, Hiziroglu Salim, Sato Masatoshi, et al., *Materials & Design,* 32 246, (2011).
37) Hejall A, Taljsten B, Motavalli M. Large-scale hybrid FRP composite girders for use in bridge structures theory, test and field application**.** Compos Part B; 36: 573–585(2005).
38) Hernandez A, Graham-Jones J, Summerscales J, Hall W. Resin transfer moulding (RTM) to produce surfboard fins with natural fibres. In: 9th International conference on composite science and technology: 2020 –scientific and industrial challenges, p. 577–83 (2013).
39) Herrmann AS, Nickel J, Riedel U. Construction materials based upon biologically renewable resources – from components to finished parts. Polym Degrad Stab;59(1 3):251–61 (1998).
40) Ho M-P, Wang H, Lee J-H, Ho C-K, Lau K-T, Leng J, et al. Critical factors on manufacturing processes of natural fibre composites. Composites Part B;43(8):3549 62 (2012).
41) Holbery J, Houston D. Natural-fiber-reinforced polymer composites in automotive applications. JOM;58(11):80–6 (2006).
42) Hossai M.F., Islam M.K. and Islam M.A., Effect of chemical treatment on mechanical and physical properties of wood saw dust particles reinforced polymer matrix composite, 10th International Conference on Mechanical Engineering, Procedia Engineering vol. 90 39 – 45, (2014).
43) Hoyos CG, Vazquez A. Flexural properties loss of unidirectional epoxy/fique composites immersed in water and alkaline medium for construction application. Composites Part B; 43: 3120–3130 (2012).
44) Kalaprasad G, Pradeep P, Mathew G, Pavithran C, Thomas S, *Composites Science & Technology,* 60 2967, (2000).
45) Kim EG, Park JK, Jo SH. A study on fiber orientation during the injection molding of fiber-reinforced polymeric composites (comparison between image processing results and numerical simulation). J Mater Process Technol;111(1–3):225–32 (2001).
46) Koon-Yang Lee, Yvonne Aitomäki, Lars A. Berglund, Kristiina Oksman and Alexander Bismarck, On the use of nano-cellulose as reinforcement in polymer matrix Composites, Composites Science and Technology (2014).
47) Ku H, Wang H, Pattarachaiyakoop N, et al. A review on the tensile properties of natural fiber reinforced polymer composites. Compos Part B Eng; 42(4): 856-873(2011).
48) Kumar SMS, Duraibabu D, Subramanian K. Studies on mechanical, thermal and dynamic mechanical properties of untreated (raw) and treated coconut sheath fiber reinforced epoxy composites. Mater and Design; 59: 63–69 (2014).
49) Larsen Thomas, Anderson Tom, Throning Bent, Horsewell Andy, Vigild Marti E, Changes in tribological behaviour of an epoxy resin by incorporating CuO nanoparticles and PTFE microparticles. Wear vol. 265 203-213, (2008).
50) Le Guen MJ, Newman RH. Pulped Phormium tenax leaf fibres as reinforcement for epoxy composites. Composites Part A;38(10):2109–15 (2007).
51) Lee Jae-Chul, Hong Young-Sun, Nan Ri-Guang, Jang Moon-Kyu, Lee Caroline S, Ahn Sung-Hoon and Kang Yeon-Jun, Soundproofing effect of nanoparticle reinforced polymer composites is studied Journal of Mechanical Science and Technology vol. 22 1468~1474, Springer (2008).
52) Lee Jonghwi and F. Yee Albert, Fracture Behaviour of Glass Bead Filled Epoxies: Cleaning Process of Glass Beads, January (2000).
53) Liu K, Zhang X, Takagi H, et al. Effect of chemical treatments on the transverse thermal conductivity of unidirectional abaca fiber/epoxy composite. Compos Part A; 66: 227–236 (2014).
54) Malkapuram R, Kumar V, Negi YS. Recent development in natural fiber reinforced polypropylene composites. J Reinf Plast Compos;28 (10):1169–89 (2009).
55) Matthews FL, Rawlings RD. Composite materials: engineering and science. Cambridge, England: Woodhead Publishing; (1999).
56) Mazraeh-shahi Talebi Z., Shoushtari Mousavi A., Bahramian A. R., A New Method for Measuring the Thermal Insulation Properties of Fibrous Silica Aerogel Composite, 5th International Biennial Conference on Ultrafine Grained and Nanostructured Materials, UFGNSM15, Procedia Materials Science vol. 11 583 – 587, (2015).
57) Mishra V, Biswas S. Physical and Mechanical Properties of Bi-directional Jute Fiber epoxy. Procedia Eng; 51: 561 – 566(2013).
58) Mohan TP, Kanny K. Water barrier properties of nano-clay filled sisal fiber reinforced epoxy composites. Compos Part A; 42: 385–393 (2011).
59) Mutasher SA, Poh A, Than AM, Law J. The effect of alkali treatment mechanical properties of kenaf fiber-epoxy composite. In: Sapuan SM, Mustapha F, Majid DL, Leman Z, Ariff AHM, Ariffin MKA, et al., editors. Composite science and technology, Pts 1 and 2; p. 191–96 (2011).

60) Mylsamy K, Rajendran I. The mechanical properties, deformation and thermomechanical properties of alkali treated and untreated Agave continuous fiber reinforced epoxy composites. Mater and Design; 32: 3076–3084 (2011).
61) Nascimento DCO, Ferreira AS, Monteiro SN, et al. Studies on the characterization of piassava fibers and their epoxy composites. Compos Part A; 43: 353–362(2012).
62) Navasa Cintia S., Reboredob María M. and Granadosa L. Dolly, Comparative Study of Agro-industrial Wastes for their use in Polymer Matrix Composites, International Congress of Science and Technology of Metallurgy and Materials, SAM –CONAMET, Procedia Materials Science vol. 8 778 – 785 (2015).
63) Newman RH, Clauss EC, Carpenter JEP, et al. Epoxy composites reinforced with deacetylated Phormium Tenax leaf fibres. Compos Part A; 38: 2164–2170 (2007).
64) Nikhil V Nayak, Composite Materials in Aerospace Applications, International Journal of Scientific and Research Publications, Volume 4, Issue 9, 1 ISSN 2250-3153, (2014).
65) Nirmal U, Hashim J, Low KO. Adhesive wear and frictional performance of bamboo fibers reinforced epoxy composite. Tribol Inter; 47: 122–133 (2012).
66) Phillips S, Lessard L. Application of natural fiber composites to musical instrument top plates. J Compos Mater;46(2):145–54 (2012).
67) Pickering K. Properties and performance of natural-fibre composites. Cambridge, England: Woodhead Publishing; (2008).
68) Pickering K. Properties and performance of natural-fibre composites. Cambridge, England: Woodhead Publishing; (2008).
69) Pramendra K Bajpai, Inderdeep Singh, Jitendra Madaan, Frictional and adhesive wear performance of natural fibre reinforced polypropylene composites, Journal of Engineering Tribology (2012).
70) Premalal HGB, Ismail H, Baharin A. Comparison of the mechanical properties of rice husk powder filled polypropylene composites with talc filled polypropylene composites. Polym Test; 21(7): 833-839 (2002).
71) Rattan R. and Bijwe Jayashree, Influence of impingement angle on solid particle erosion of carbon fabric reinforced polyetherimide Composite, Industrial Tribology Machine Dynamics and Maintenance Engineering Centre (ITMMEC), Indian Institute of Technology Delhi, Hauz Khas. Wear vol. 262 568–574, (2007).
72) Reif Martina, Zach Jiri, Hroudova Jitka, Studying the properties of particulate insulating materials on a natural basis, International Conference on Ecology and new Building materials and products, Procedia Engineering vol. 151 368 – 374, (2016).
73) Rodriguez E, Petrucci R, Puglia D, Kenny JM, Vazquez A. Characterization of composites based on natural and glass fibers obtained by vacuum infusion. J Compos Mater;39(3):265–82 (2005).
74) Romli FI, Alias AN, Rafie ASM, et al. Factorial Study on the Tensile Strength of a Coir Fiber-Reinforced Epoxy Composite. AASRI Procedia; 3: 242 – 247 (2012).
75) Rong MZ, Zhang MQ, Liu Y, Yang GC, Zeng HM. The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites. Compos Sci Technol;61(10):1437–47 (2001).
76) S Shivakumar, Guggari G. S. , Faculty, Dept. of I&PE, Gogte Institute of Technology, Belgaum, Karnataka, India, Literature Review of Fiber Reinforced Polymer Composites International Journal of Advances in Engineering & Technology, ©IJAET, (2011).
77) S Sivasaravanan, Bupesh Raja V.K. , Manikandan, Impact Characterization of Epoxy LY556/E-Glass Fibre/ Nano Clay Hybrid Nano Composite Materials, 12th Global Congress on Manufacturing and Management, Procedia Engineering vol. 97 968 – 974, (2014).
78) Sarikanat M, Seki Y, Sever K, et al. Determination of properties of Althaea Officinalis L. (Marshmallow) fibres as a potential plant fibre in polymeric composite materials. Compos Part B,; 57: 180–186(2014).
79) Shah DU, Schubel PJ, Clifford MJ. Can flax replace E-glass in structural composites? A small wind turbine blade case study. Composites Part B;52:172–81 (2013).
80) Sherely Annie Paul, Abderrahim Boudenn, Laurent Ibos, Yves Candau, Kuruvilla Joseph, Sabu Thomas, *Composites: Part A*, 39 1582 (2008).
81) Singh B, Gupta M, Verma A. Influence of fiber surface treatment on the properties of sisal-polyester composites. Polym Compos;17(6):910–8 (1996).
82) Sreenivasan VS, Soma Sundram S, Ravindran D, Manikandan V, Naryanaswamy R, Materials and Design, 32 453, (2011).
83) Srinivas K., Bhagyashekar M.S., Wear Behaviour of Epoxy Hybrid Particulate Composites (Hybrid PMC), Procedia Engineering vol. 97 488 – 494, (2014).
84) Srisuwana S, Prasoetsophaa N, Suppakarna N, et al. The Effects of Alkalized and Silanized Woven Sisal Fibers on Mechanical Properties of Natural Rubber Modified Epoxy Resin. Energy Procedia; 56: 19 – 25, (2014).
85) Summerscales J, Dissanayake NPJ, Virk AS, Hall W. A review of bast fibres and their composites. Part 1 – fibres as reinforcements. Composites Part A;41(10):1329–35 (2010).
86) Symington MC, Banks WM, West Opukuro David, Pethrick RA., Journal of Composite Materials, 43 1083, (2009).
87) Tanaka K., Fukushima Y., Kashihara K. & Katayama T., Effect of water absorption on the mechanical properties of continuous carbon fibre reinforced polycarbonate composites. High-Performance Structures and Materials V, (2010).
88) Uddin N, Kalyankar RR. Manufacturing and structural feasibility of natural fiber reinforced polymeric structural insulated panels for panelized construction. Int J Polym Sci 963549 (2011).
89) Wambu Paul, Ivens Jan, Verpoest Ignaas, Natural fibres: can they replace glass in fibre reinforced plastics? , Composites Science and Technology vol. 63 1259–1264 (2003).
90) Wang Ru-Min, Zheng Shui-Rong, and Zheng Ya-Ping, Polymer matrix composite and technology Woodhead Publishing in materials,(2011).
91) Węcławski BT, Fan M, Hui D. Compressive behaviour of the natural fibre composite. Compos Part B;

67: 183–191 (2014).
92) Wu XF, Dzenis YA. Droplet on a fiber: geometrical shape and contact angle. Acta Mech;185(3– 4):215–25 (2006).
93) Yang QS, Peng XR, Kwan AKH. The strain energy release rate for interfacial cracks in hybrid beams. Mech Res Commun; 33: 796–803(2006).
94) Yousif BF, Nirmal U, Wong KJ. Three-body abrasion on wear and frictional performance of treated betel nut fiber reinforced epoxy (T-BFRE) composite. Mater and Design; 31: 4514– 4521 (2010).
95) Youssef AM, El-Samahy MA, Rehim MHA. Preparation of conductive paper composites based on natural cellulosic fibers for packaging applications. Carbohydr Polym;89(4):1027–32 (2012).

