International Journal of Advance Research in Science and Engineering
Volume No.06, Issue No. 10, October 2017
www.ijarse.com
IJARSE
ISSN: 2319-8354

Plant Fiber Reinforced Polymer Matrix Composites: A Review

B. Ravi[1], B. Siva Ramakrishna[2]

[1]Assistant Professor, [2]UG Student, Department of Mechanical Engineering,
SBIT, Khammam, Telangana (India)

ABSTRACT

The development of high performance engineering products made from natural resources is increasing work wide, due to renewable and environmental issues. Natural fiber reinforced polymer composites have many advantages like availability, inexpensive, renewable, minimal health hazards, relative high specific strength and modulus, lightweight and biodegradable. However, the physical properties of natural fiber had large variation according to plant originality, plant maturity, location in plant, retting and treatment technique and composite processing technique. Natural fibers are emerging as cost effective and apparently ecologically superior substitutes to glass fibers in composites. Therefore, this paper presents an over view of the developments made in the area of plant fiber reinforced polymer matrix composites in terms of their market, manufacturing methods, and overall properties. These include plant fiber preparation, composite fabrication technique, and composite material.

Keywords: Plant fiber; composite, Mechanical; thermal.

I. INTRODUCTION

Polymer matrix composites are mostly commercially produced composite in which resin is used as matrix with different reinforcing materials. Polymer (resin) is classified into two types; thermo plastics and thermo sets which reinforces different types of fibers natural and man-made fiber for different applications. Due to increase in population, natural resources are being exploited substantially as on alternative to synthetic materials. Natural fibers present many advantages compared to synthetic fibers which make them attractive as reinforcements in composite materials. They come from abundant and renewable resources, which ensures a continuous fiber supply and a significant material cost saving to the plastics industry. Unlike brittle fibers, such as glass and carbon fibers, cellulose fibers are flexible and will not fracture when processed over sharp curvatures [28]. Now a days, various types of natural fibers [1] have been investigated for use in composites including flax, hemp, jute straw, wood, rice husk, wheat, barley, oats, rye, cane (Sugar and bamboo), grass, reads, kenaf, ramie, oil palm, sisal, coir, water hyacinth, pennywort, kapok, paper mulberry, banana fiber, pineapple leaf fiber and papyrus[18].For the these reasons synthetic fiber reinforced polymers have emerged as a major class of structural materials and are widely used as substitution for metals in many weights critical components in air craft, aero space, auto motive, marine and other industries [2]. The interest encompasses a wide variety of shapes and materials ranging from synthetic to natural, in order to fulfill the demands of producing composites with desired properties. In corporations of reinforcements, such as fibers and fillers in to composites affords means of extending an improve in the properties of the composites that meets the requirements of most engineering applications [3]. Consequently, these improvements will be associated with economic advantages such as low production cost and resin consumptions [4].

In this scientific review article, the overall characteristics of the natural plant reinforced composites, in terms of mechanical properties, thermal properties as well as water absorption properties will be reviewed and the manufacturing process will be discussed.

II. NATURAL (PLANT) FIBER COMPOSITES

Over the past few decades there has been a growing interest in the use of natural fibers in composite applications. These types of composites present many advantages compare to synthetic fibers such as low tool wear (5), low density, cheaper cost, availability and bio- degradability [6]. The most common natural plant used in applications is bast fibers such as hemp, jute, flax, kenaf and Ramie [7].

Natural fibers are subdivided based on their origins i.e., whether they are derived from plant, animals, or minerals, as shown in fig. 1. According to study groups, plant fibers are the most popular of the natural fibers, used as reinforcement in fiber reinforced composites. Plant fibers include bast (or stem, soft, or sclerenchyma) fibers, leaf or hard fibers, seed, fruit, wood, cereal straw, and other grass fibers. Plant fibers are composite materials designed by nature. The fibers are basically comprised of a rigid, crystalline cellulose micro fibril reinforced amorphous lignin, and/or hemicelluloses matrix. Most plant fibers, except for cotton, are composed of cellulose, hemicelluloses, lignin, waxes, and several water-soluble compounds; where cellulose, hemicelluloses, and lignin are the major constituents.

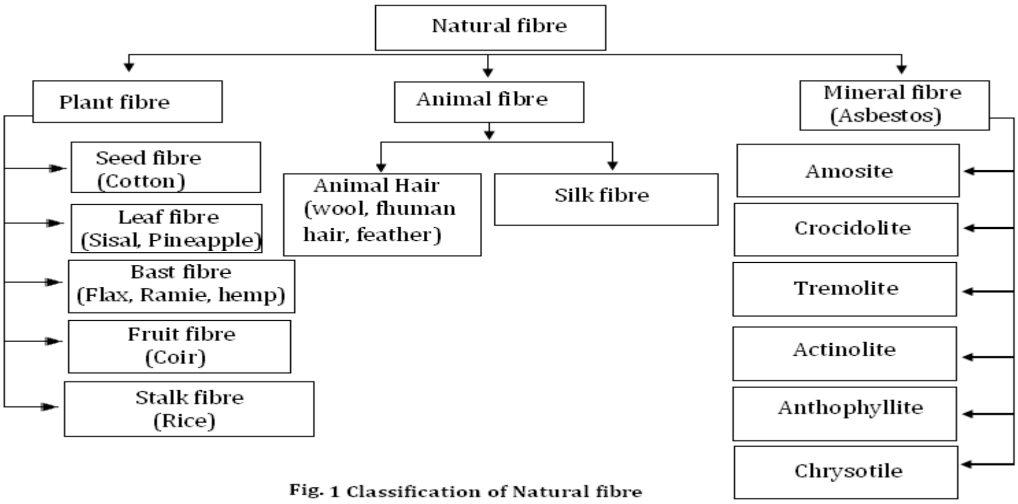

Fig. 1 Classification of Natural fibre

Table 1. Characteristic value for the density, mechanical properties of natural (plant) and synthetic fibers

Fiber	Density	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)
Flax	1.5	345-1500	27.6	2.7-3.2
Hemp	1.47	690	70	1.6
Jute	1.3-1.49	393-800	13-26.5	1.16-1.5
Ramie	1.55	400-938	61.4-128	1.2-3.8
Sisal	1.45	468-700	9.4-22	3-7
Cotton	1.5-1.6	287-800	5.5-12.6	7-8
Coir	1.15-1.46	131-220	4-6	15-40
E-glass	2.55	3400	73	2.5
Kevlar	1.44	3000	60	2.5-3.7
Carbon	1.78	3400^{a}-4800^{b}	240^{b}-425^{a}	1.4-1.8

[a] Ultra high modulus carbon fibers

[b] Ultra high tenacity carbon fibers

III. PROPERTIES OF NATURAL (PLANT) FIBER REINFORCED COMPOSITES

3.1 Mechanical Properties

The mechanical properties and physical properties of natural fibers vary considerably depending on the chemical and structural composition, fiber type and growth conditions. The performances of materials is always presented in terms of their mechanical characteristics, such as tensile properties, flexural properties, compression properties, impact properties and wear behavior. These characteristics are important to determine material ability, especially under extreme and critical conditions, which are directly conducted with engineering performance [15, 16-17]. Some of the mechanical properties of plant fiber reinforced composites are : Ultimate strength (the maximum engineering stress in tension that may be sustained without fracture, often known as tensile strength), fracture strain (stress at fracture from a bend or flexure test), flexural modulus (an inclination of a materials stiffness when flexed, which is the ratio, within the elastic limit, of the applied stress on a test specimen in flexure , to the corresponding strain in the outer most fibers of the specimen): and impact strength (the degree of resistance of any material to impact loading, with (or) without a notch in it).

Mechanical structure of plant fibers is much lower when compared to those of the most widely used competing reinforcing glass fibers. However, because of their low density, the specific properties (property-to-density ratio). Strength and stiffness of plant fibers are comparable to the values of glass fibers [1, 21]. Table 1 summarizes characteristic values for the density and mechanical properties, of natural (plant) and synthetic fibers.

International Journal of Advance Research in Science and Engineering
Volume No.06, Issue No. 10, October 2017
www.ijarse.com
IJARSE
ISSN: 2319-8354

In summary, a composite study of the mechanical properties of natural (plant) fiber reinforced composites with synthetic fibers, is collected together, and shown in figs.2, 4 and 5. Tensile strength of synthetic fibers is more compared to natural fibers. In natural fibers, bast fibers have more tensile strength when compared to leaf fiber and seed fiber. Fruit fibers has very low tensile strength and higher in elongation at break. Meanwhile fig.3 illustrates that, these bast fibers have a higher modulus than seed fiber, leaf fiber, fruit fiber and less value than synthetic fibers.

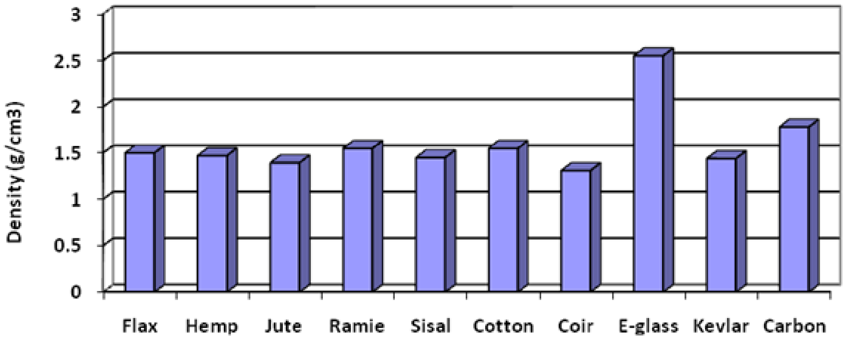

Figure 2. Comparison of Density of Natural Fibers with Synthetic Fibers

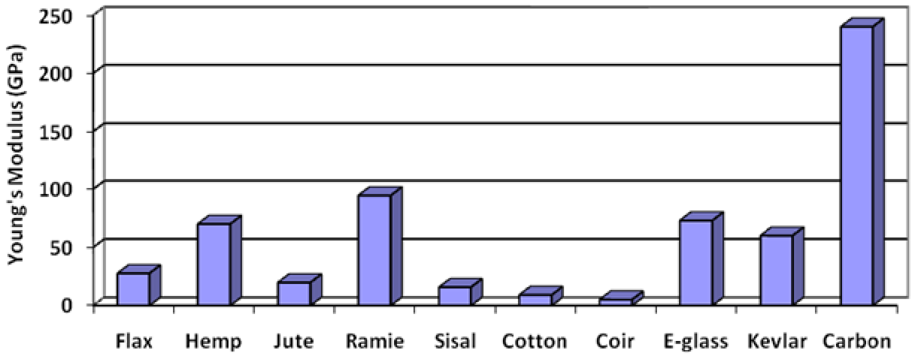

Figure 3. Comparison of Young's Modulus of Natural Fibers with Synthetic Fibers

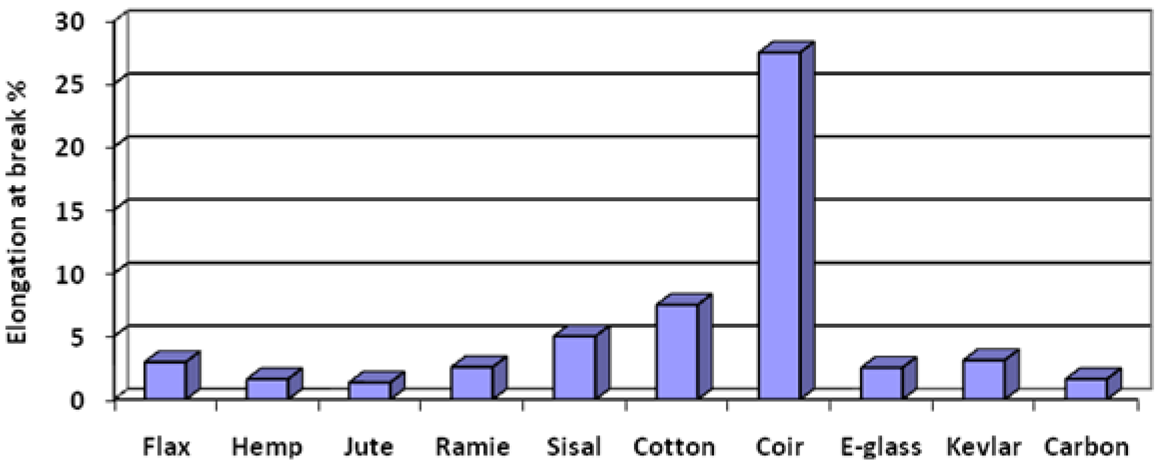

Figure 3. Comparison of Elongation of Natural Fibers with Synthetic Fibers

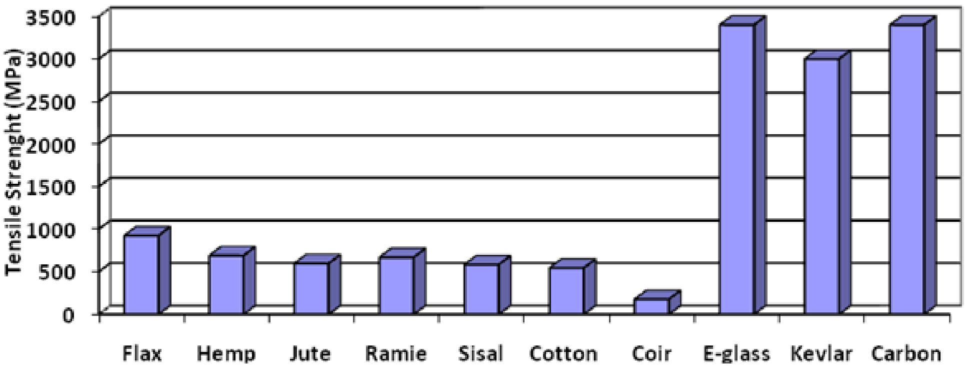

Figure 5. Comparison of Tensile Strength of Natural Fibers with Synthetic Fiber

3.2 Thermal Properties

Thermal analysis studies are another essential characterization, which needs to be considered to fully distinguish the overall behavior of plant fiber reinforced composite. For this reason, three regular characterization methods were employed, namely Different Scanning Calorimetric (DSC), Thermo Gravimetric Analysis (TGA), and Dynamics Mechanical Analysis (DMA). From the DSC several crucial parameters could be estimated, such as the glass transition temperature (Tg), melting temperature, crystal line level and oxidation [12]. Mean while, from the TGA measurement, the mass of the sample as a function of the temperature can be measured. Changes of mass usually occur during sublimation, evaporation, decomposition and chemical reaction and magnetic or electrical transformation of the material that is directly related to thermal stability [13]. The DMA measurement consists of observation of the time – dependent deformation behavior x(t) of a sample under periodic, mostly sinusoidal deformation force with very small amplitudes F(t). Thus it is possible to calculate, for example, young’s modulus E1 (Storage Modulus) and E11 (Loss Modulus) as well as mechanical loss factor, tan δ (damping), as a function of temperature and deformation [14].

3.3 Water absorption Properties

Should Water absorption of natural fiber reinforced composites is a serious concern; especially for their potential outdoor applications. For a given composite system, the water absorption characteristic depends on the content of the fiber, fiber orientation, temperature, area of the exposed surface, permeability of fibers, void content, and the hydrophilicity of the individual components [20,10 –11].

In water absorption test, at least three specimens of each material were tested. All specimens were dried in an oven for 24 h at 600C and weighed before immersion in a distilled water bath at different temperatures. The specimens were periodically removed from the water bath, wiped free of surface moisture, immediately weighed to the nearest 1 mg and then replaced into the water bath.

In order to determine the effect of water uptake on the mechanical properties of the composites, different specimen dimensions were required. Three specimens from each material were taken after immersion in water for 40 days at 65 0C and frozen at 180C for 24 h. These specimens were then thawed and tested in tension to determine if the expansion of the absorbed water during freezing had affected the tensile performance of the composites [30].

IV. FIBER TREATMENT

4.1 Alkali Treatment

The samples were washed with sodium hydroxide (NaOH) to lose some amount of lignin so that certain active sites (hydroxyl groups) could be formed at the surface, which would facilitate water absorption. Fibers were immersed in NaOH solution at different concentrations (0.5, 2, and 5%) for half, one and two hours. Later they were washed several times using cold tap water. These fibers were then dried in an air oven at 60^{o}C for 24 hrs.

4.2 Acetylation

Untreated fibers were immersed in 18% aqueous NaOH solution at 28^{o}C for 1 hr. These fibers were washed several times with cold water finally with acidified water (0.1 N HCL). These fibers were dried in an air oven and then soaked on glacial acidic acid for 1 hr at the same temperature.

4.3 Permagnate Treatment

The alkali treated fibers were soaked with $KMnO_4$ solution in acetone for 1 minute. This was decanted and the fibers were dried in air.

4.4 Heat Treatment

Fibers were heated at 150oC in an air circulating oven for 4 hrs. The weight loss was measured when the fiber was cool down to room temperature [29].

V. COMPOSITE FABRICATION

There are several methods for making of natural fiber composites. Most of the techniques commonly used for making glass fiber composites are applicable for making natural fiber composites. However, the well known method for composites making are as follows:

5.1 Hand Lay – up/Spray up

Hand Lay – up/Spray up is one of the cheapest and most common processes for making fiber composite products. In this process, the mold is waxed and sprayed with gel coal and cured in a heated oven. In spray up process, catalyzed resin is sprayed into the mold, with chopped fiber where secondary spray up layer imbeds the core between the laminates resulting a composite. In hand layup processing, both continuous fiber strand mat and fabrics are manually placed in the mold. Each ply is sprayed with catalyzed resin and with required pressure compact laminate is made.

5.2 Resin transfer molding (RTM)

In a Resin Transfer Moulding (RTM) the glass mat is first heated and pressed into a mould to create a preform. Resin is then injected or transferred into the mould to create the composite component. As the glass mat is pressed into the mould the arrangement of the fibers may be distorted from that originally designed. RTM provides high quality finished surface on both the sides of composite with a relatively low energy makes perfect shapes. The fabricator generally gel coats the mold halves, then lays continuous or chopped strand mat and closes the mold. Resin transfers into mold through injection pressure, vacuum pressure, or both. Cure temperature depends on the resin system.

5.3 Compression molding

Compression molding is a molding technique for making composite materials with low unit cost with faster cycle times. Components may be manufactured from a compression moulded composite material such as Glass Mat Thermoplastic (GMT) or Sheet Moulding Compounds (SMC). GMT usually consists of continuous random glass fibers in a polypropylene matrix, whilst SMC usually consists of 25mm long random glass fiber in a polyester matrix with calcium carbonate filler. Sheet Molding Compounds (SMC) is a sheet that sandwiches fiber between two layers of resin paste. Fiber/Fabric drop onto the paste and a second film carrier faces with another layer of resin. When the SMC is ready for molding, the mold is closed, clamped, and between 500 to 1,200 psi pressure is applied. After curing, mold is opened and the sheets were removed manually or through an injector system and ready for use.

5.4 Injection Moulding

Injection moulding refers to a process that generally involves forcing or injecting a fluid plastic material into a closed mould. Injection molding is a fast, high volume, low pressure, and closed process. Injection speeds are typically 1-5 s and nearly 2,000 small parts can be produced per hour. A ram or screw type plunger forces a material shot through the machine’s heated barrel and injects it into a closed, heated mold. Heat build-up is carefully controlled to minimize curing time. After cure and injection, parts need only minimal finishing. Filament winding is an automated, high volume process that is ideal for manufacturing pipe, tank, shafts and tubing, pressure vessels, and other cylindrical shapes. The winding machine pulls dry fibers form supply racks through a resin bath and winds the wet fiber around a mandrel. This method a normally used for high-volume and low-cost component manufacturing. The disadvantage of the method is that it is limited to materials with very short lengths. Also, since there is large amount flow during the process, material non-uniformities do exist.

5.5 Pultrusion

Evolution of manufacturing processes of polymer composites has introduced the unique technique of the pultrusion process. Recently, this technology has been and, given all of the available evidence, is likely to remain a very attractive application and growth sector of the whole polymer composites industry. Moreover, pultruded profiles are already recognized as a high quality industrial product, capable of satisfying a wide range of high performance and structural element requirements [26]. Pultrusion is the continuous, automated closed-molding process that is cost effective for high volume production of constant cross sectional parts. Pultruded custom profiles include standard shapes such as channels, angles, beams rods, bars, tubing and sheets [22].

VI. OPPORTUNITIES AND CHALLENGES

The use of plant fibers as reinforcement in composite materials is finding increasing interest in the automotive and building industry, and the properties of plant fiber composites have been addressed in numerous research studies. New composite materials based on plant fibers and polymers are being increasingly used in the building industry and in automotive industry. Plant fibers, such as sisal, jute, hemp, flax, palm etc can be used as reinforcement for Epoxy, polyester, PVC, PE or PP-type polymers in place of synthetic fibers (glass, Kevlar, carbon, etc). This substitution offers many benefits:

- Economic: lower costs on account of significantly reduced cycle times, energy savings.
- Technical: mechanical properties identical to those of traditional reinforcements, reduced tool wear and tear, high geometric stability of the manufactured parts, good insulation characteristics;
- Environmental: renewable resource, easy to recycle, no material toxicity, reduced fossil fuels content, CO2-neutral materials.

Natural fiber composite materials are being used for manufacturing many components in the automotive sector [1, 21, 22, 23, 24-25]. Like glass, the natural fibers combine readily with a thermoplastics or thermosetting matrix to produce commodity goods. Typical market specification natural fiber composites includes ultimate breaking force and elongation, impact strength, flexural properties, acoustic absorption, fogging characteristics, flammability, and suitability for processing: temperature and dwell time, odor, water absorption, dimensional stability and crash behavior [27]. Plant fibers are mainly used in the interior parts making of passenger cars and truck cabins.

Prospects for the use of plant fiber in Automotive locomotive, aerospace, construction industry has long way to go to meet the societal area. In railways, the gear case, main doors, luggage racks, floor/roof panels, berths, chair backings, interior panels and partitions, interior furnishing and seating. Modular toilets and lightweight coaches are made from different natural fiber composites and their combinations. Composite materials offer some significant advantages to metals in many structural applications in railways to the effect that they are lightweight, cost-effective, corrosion resistant energy saving [21]. Development of biodegradable materials as an alternative to synthetic materials such as glass fiber-reinforced plastic and other synthetic plastics is the challenge for the present and future generations in the context of global climate change.

VI. CONCLUSIONS

From this short review, it is clear that the interest of utilizing plant fiber as reinforced materials in polymer matrix composite are discussed. This was forced by the need of eco-friendly material for sustainable development. However, there are numbered of factors should be considered and improved before this plant fiber based product can be widely accepted in a global market.

- Large variation in fiber properties due to various types of plant fiber, plant maturity, plant originality, location in plant and retting process.
- Nature of plant fiber where their strong polar character creates incompact ability with most polymer matrices. Thus, the mechanical properties of natural fiber reinforced composite are influenced mainly by the adhesion between matrix and fiber.
- Natural fiber have good prospective as reinforcements in polymers (thermo plastics, thermosets and elastomers) composites. Due to the high specific properties and low density of natural fibers, composites based on these fibers may have good implications in industry.

All authors are required to complete the Procedia exclusive license transfer agreement before the article can be published, which they can do online. This transfer agreement enables Elsevier to protect the copyrighted material for the authors, but does not relinquish the authors' proprietary rights. The copyright transfer covers the exclusive rights to reproduce and distribute the article, including reprints, photographic reproductions, microfilm or any other reproductions of similar nature and translations. Authors are responsible for obtaining from the copyright holder, the permission to reproduce any figures for which copyright exists.

REFERENCES

[1] Taj S., munawar, M.A., & Khan, S.U. (2007). Review: Natural fiber-reinforced polymer composites. Proc Pakistan Acad Sci, Vol 44, No.2, pp. (129-144).

[2] Mallick, P.K., fiber reinforced composite materials, manufacturing and design. Third Edition ed. 2008 130 ca raton: CRT press and Talyler & Francis group.

[3] H.M. Akil, M.F. Omar, A.A.M. Mazuki, S. Safiee, Z.A.M Ishak, A. Abu Bakar. Review: Kenaf fiber reinforced composites. Materials and Design 32 (2011) 4107-4121.

[4] Aziz SH, Ansell MP. The effect of alkalization and fiber alignment on the mechanical and thermal properties of kenaf and hemp bast fiber composites: part 1-polyester resin matrix. Compos Sci Technol 2004; 64:1219-31.

[5] Wambua P, Ivens J, Verpoest I. Natural fibers: can they replace glass in fiber reinforced plastics? Compos Sci Technol 2003;63:1259-64.

[6] Nishino T, Hirao K, Kotera M, Nakamae K, Inagaki H. Kenaf reinforced biodegradable composite. Compos Sci Technol 2003;63:1281-6.

[7] Kozlowski R, Mieleniak B, Helwig M, Przepiera A. Flame resistant lignocellulosic-mineral composite particleboards. Polym Degrad Stabil 1999;64:523-8.

[8] Md. Yussni Hashim, Ahmad Mujahid Ahmad Zaidi, Saparudin Ariffin; Plant fiber reinforced polymer matrix composite: a discussion on composite fabrication and characterization technique.

[9] Chawla KK, Fibrous materials. United Kingdom: Cambridge University Press;1998.40. Dhakal H, Zhang Z, Richardson M. Effect of water absorption on the mechanical properties of hemp fiber reinforced unsaturated polyester composites. Compos Sci Technol 2007;67:1674-83.

[10] Chow C, Xing X, Li R. Moisture absorption studies of sisal fiber reinforced polypropylene composites. Compos Sci Technol 2007;67:306-13.

[11] Nosbi N, Akil HM, Mohd Ishak ZA, Abu bakar A. Degradation of compressive properties of pultruded kenaf fiber reinforced composites after immersion in various solutions. Mater Des 2010;30:4960-4.

[12] Qu X, Wirsen A, Albertsson AC, Effect of lactic/glycolic acid side chains on the thermal degradation kinetics of chitosan derivatives. Polymer 2000;41:4841-7.

[13] Julkapli NM, Akil HM. Thermal properties of kenaf-filled chitosan biocomposites. Polym Plast Technol Eng 2010;49:147-53.

[14] Mazuki AAM, Akil HM, Safiee S, Ishak ZAM, Bakar AA. Degradation of dynamic mechanical properties of pultruded kenaf fiber reinforced composites after immersion in various solutions. Compos Part B: Eng 2010.

[15] Rowell RM, Sanadi A, Jacobson R, Caulfield D. Properties of kenaf/polypropylene composites. Kenaf properties. Processing and products. Mississippi: Ag & Bio Engineering; 1999.

[16] Omar MF, Md Akil H, Ahmad ZA, Mazuki AAM, Yoloyama T. Dynamic properties of pultruded natural fiber reinforced composites using Split Hopkinson Pressure Bar technique. Mater Des 2010;31:4209-18.

[17] Chow P, Lambert RJ, Bowers C, McKenzie N. Physical and mechanical properties of composte panels made from kenaf plant fibers and plastics;2000.p. 139-43.

[18] Mohini Saxena, Asokan Pappu, Anusha Sharma, Ruhi Haque and Sonal Wankhede; Composite materials from Natural Resources: Recent Trends and Future Potentials. CSIR- Advanced Materials and Processes Research Institute, Bhopal- India.

[19] Bismarck A, Mishra S, Lampke T. Plant fibers as reinforcement for green composites. Mohanty AK, Mishra M, Drzal LT, editors. Natural fibers, biopolymers and biocomposites. Boca Raton (FL): CRC Press: 2005.

[20] Dhakal H, Zhang Z, Richardson M. effect of water absorption on the mechanical properties of hemp fiber reinforced unsaturated polyester composites. Compos Sci Technol 2007;67:1674-83.

[21] Saxena, M., Pappu, A., Haque, R., & Sharma, A. (2011). Sisal fiber based polymer composites and their applications cellulose fibers: bio- nad nano-polymer composites. Springer book ISBN 13 783642173691.

[22] Saxena, M., Asokan, P., & Bakshi, P. (2008). Sisal potential for engineering application- an overview. In: Sisal fiber technologies for sustainable rural employment generation. Allied publications, New Delhi, pp. (112-154).

[23] Karus, M., & Gahle, G.C. (2006). Use of natural fibers in composites for the German automotive production from1999 till 2005. Slowed growth in the past two year's new production techniques arising. Nova-Institute, Hurth

[24] Mohanty, A.K., Misra, M., & Drzal, L.T. (2005). Natural biopolymers and bio composites (1 edition), CRC press, ISBN 084931741X.

[25] Xin, X., Xu, C.G., & Qing, L.F. (2007). Friction properties of sisal fiber reinforced resin brake composites. Wear,Vol. 262, PP. (736-741).

[26] Van de Velde K, Keikens P. thermoplastic pultrusion of natural fiber reinforced composites. Compos Struct 2001; 54:355-60.

[27] Rousin D, sain M, Couturier M. Resin transfer molding of natural fiber reinforced composites: cure simulation. Compos Sci Technol 2004;64:629-44.

[28] Dr. Navdeep Malhotra, Khalid Sheikh, Dr. Sona Rani ' A review on mechanical characterization of natural fiber reinforced polymer composites'-JERS/Vol.III/IssueI/Jan-March-2012/75-80.

[29] Savita Dixit and Preeti Verma 'The effect of surface modification on the water absorption behavior of coir fibers'-Advances in applied research, 2012, 3 (3): 1463-1465.

[30] H. Deng, C.T. Reynolds, N.O. Cabrera, N.M. Barkoula, B. Alcock, T. Peijs 'The water absorption behavior of all-polypropylene composites and its effect on mechanical properties' composites: Part B 41 (2010) 268-275.