

# *Natural Fibres in Engineering Applications : An Overview*

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**Abstract**— An overview of literature on various types of surface treatments applied to natural fibres and the resultant enhancement in properties is presented in this paper. Important variables that determine the overall properties of fibres are their structure, microfibrillar angle, cell dimensions, defects and the chemical composition. Structure and composition of various types of natural fibres and their applications are also brought into perspective. Degradation behaviour of natural fibres and various mechanisms involved are also discussed. Various treatment methods adopted in practice include alkali treatment, alkali-steam treatment, enzyme treatment, transesterification using vegetable oils, UV grafting with monomers, physical coatings, treatment using specific chemicals and natural antimicrobial finishing. Advancements made in the field of these techniques have been discussed briefly. Effect of such treatments on various properties is also included in this paper.

**Keywords**—natural fibres; chemical modifications; geotextiles; composites

## I. INTRODUCTION

Due to simultaneous awareness increase on environment and energy, increasing attention is being paid to natural fibres with a view to conserving energy and protecting the environment [1]. A huge range of natural fibres is available, with some having very high initial tensile strength. Natural fibres exhibit progressive loss of strength with time. Rate of loss of such strength varies among the fibres. Hence it is possible to 'tailor' composites of natural fibres to produce a material with the required strength-time profile for a variety of engineering situations [2]. The renewed interest in the natural fibres has resulted in large number of modifications to bring it at par and even superior to synthetic fibres [3]. Limited life geosynthetics made of natural fibres such as coir and jute are used in solving various ground engineering problems where loss of strength of natural fibres with time is accounted for [4].

## II. NATURAL FIBRES

### A. Structure and composition

Natural fibres include those originate from plant, animal and mineral sources. Plant based natural fibres are lignocellulosic in nature and are comprised of cellulose, hemicelluloses, lignin, pectin and waxy substances. These

fibres are otherwise known as Lignocellulosic Fibres (LCFs). Lignin is a complex hydrocarbon polymer which gives rigidity to the stem. It provides protection to fibre against biological attack. Crystallinity of cellulose determines the reinforcing ability of fibre. Hemicellulose forms the cementing matrix and is hydrophilic in nature. Pectin provides flexibility to fibre [5]. Chemical composition of various plant fibres are listed in Table I [6]. The cell wall in a fibre is not a homogenous membrane. Each fibre has a complex, multi-layered structure as shown in Fig. 1 [6]. Cell wall is made up of lignin, cellulose, hemicelluloses and pectin. First layer is the thin primary wall and it is the initial layer deposited during cell growth. The secondary wall is made up of three layers and the thick middle layer determines the mechanical properties of the fibre. The middle layer consists of a series of helically wound cellular microfibrils formed from long chain cellulose molecules. Microfibrils are bound by amorphous lignin matrix and are attached to the stem by pectin. The angle between the fibre axis and the microfibrils is called the microfibrillar angle. Microfibrils provide mechanical strength to the fibre. In a natural fibre, cellulose is responsible for strength of fibres, hemicelluloses for thermal, biological and moisture degradation, while lignin for UV degradation and char formation. Thus, the important variables that determine overall properties of fibres are its structure, microfibrillar angle, cell dimensions, defects and the chemical composition [3, 7].

### B. Applications

Engineers are being challenged to adopt environment friendly approach in many aspects of engineering disciplines. This insists on the utilisation of biodegradable or recyclable materials. Natural fibre reinforced composites made of fibres such as hemp, kenaf, jute, and bamboo are finding their way in automobile and construction industry [8].

Use of natural materials, such as jute, coir and bamboo, as reinforcing materials in soil is prevalent for a long time [9]. It has been investigated that the addition of natural fibres to soil will improve the ductility behaviour of the soil there by reducing the development of crack during shrinkage [10].

The key to developing geosynthetics from natural fibres is the concept of designing by function, i.e. identifying the

TABLE I. COMPOSITION OF NATURAL FIBRES [6]

Fibre	Cellulose	Hemicellulose	Pectin	Lignin	Extractives	Fats & waxes
	% dry weight					
Cotton	91.8	6.3	--	--	1.1	0.7
Flax (bast)	71.2	18.5	2.0	2.2	4.3	1.6
Hemp (bast)	78.3	5.4	2.5	2.9	--	--
Jute (bast)	71.5	13.3	0.2	13.1	1.2	0.6
Coir (brown)	35.6	15.4	5.1	32.7	3.0	--
Coir (white)	36.7	15.2	4.7	32.5	3.1	--
Coir pith	19.9	11.9	7.0	53.3	0.3	--
Sisal	73.1	13.3	0.9	11.0	1.3	0.3
Abaca	70.2	21.7	0.6	5.6	1.6	0.2

functions and characteristics required to overcome a given problem. A well engineered design can result in natural fibre materials which can compete with synthetic materials and sometimes they will even have superior performance [4]. For load-bearing applications, the use of reinforcements in the form of continuous aligned fibres is essential, so that the full efficiency of fibre is utilised. As technical plant fibres possess only discrete length, they need to be processed into yarns and then converted to a continuous product with highly controlled fibre orientation ie., textile reinforcements [11].

Natural geosynthetics made of natural fibres such as coir and jute is being increasingly used in various civil engineering applications to solve a variety of problems. Coir geotextile has prominent role in improving the properties of soil to be utilized in pavements. Soils which exhibit low shear strength and high compressibility can be improved by the use of coir geotextiles [12].

The concept of soil reinforcement with tensile elements has been widely accepted in engineering practice [9]. Natural geotextile can be used as an effective reinforcing material for temporary clay structures in the wetland environment [13]. Geotextiles made of natural fibres are increasingly finding a place in erosion control [14, 15]. Good performance of coir geotextiles has been reported in drainage installations as vertical drains and blanket drains in embankments [14, 16]. Geotextile from jute impregnated with rot resistant bitumen has been found to serve as a successful fabric form and probable secondary liner [17]. The feasibility of using of coir geotextiles as attachment media in filters for treatment of wastewater is also reported [18].

C. Advantages and disadvantages

Some major plus points about natural fibres are that they are relatively inexpensive, easy to process and renewable. They have a reduced carbon footprint and enhanced recovery at the end of lifecycle [19]. Natural fibres such as jute have high tensile strength and modulus, good dimensional stability, anti-slip nature, high moisture absorption and biodegradability. However, low extensibility, stiffness, long hairs protruded from the yarn surface and fibre shedding are the important drawbacks which restrict their processibility in subsequent high-speed machines [20]. High biodegradability of natural fibres sometimes poses problems in some engineering applications. Certain fibres such as sisal fibre have very high initial tensile strength. It is strong as the equivalent polyester fibre which itself would be about three times the strength of the corresponding coir fibre. Coir exhibits very slow, progressive loss of tensile strength with time. It does not degrade in saline environment [21]. Coir is among the strongest and most durable natural fibres, due to high lignin content [14, 16]. Woven coir geotextiles are observed to exhibit high tensile strength and pull out resistance [22]. Hemp fibres possess high suppleness and resistance within an aggressive environment [8]. Natural fibres such as kenaf, hemp, flax and jute find their application in composites as they offer significant reduction in weight, cost

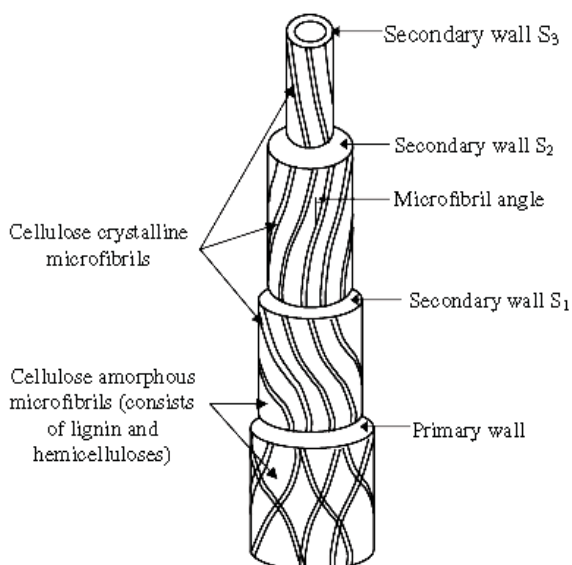


Fig. 1. Structure of natural fibre [6].

and CO<sub>2</sub> [23]. Cotton is a non allergic natural fibre with high extensibility [4].

Although natural fibres are cheap compared to artificial fibres, there is possibility of biodegradation during long run [10]. Natural fibre reinforced composites become less attractive due to lack of good interfacial adhesion, low melting point and poor resistance towards moisture. These make pre-treatment processes necessary in order to clean and chemically modify the surface, stop the moisture absorption process and increase the surface roughness [3]. Despite their relative advantages, geotextiles based on natural fibres find limited use in many engineering projects because of their relatively low tensile strengths and their susceptibility to biological, chemical and physical degradation [24]. Usage of natural fibres in civil engineering applications is limited mainly due to their tendency to degrade under different environmental conditions [7].

#### D. Degradation Mechanisms

All LCFs contain free hydroxyl and other oxygen-containing groups which exhibit a tendency to attract water molecules through hydrogen-bond formation causing the fibres to swell. Due to this swelling, the cellulose molecules get exposed to microbial attacks, which degrade the cellulose and cause strength loss. On exposure to chemical environment, reactions occur due to hydrolysis, oxidation or dehydration which results in loss of tensile strength in fibres [25].

The problem of durability of natural fibres is complex and contradictory and it depends on several factors or combination of factors such as ambient moisture content, degree of acidity/alkalinity, etc. Under ambient conditions favourable for the growth of bacteria, microbial degradation of fibres takes place [4, 26]. Fungi, along with other microbes, chiefly bacteria are responsible for the microbial decomposition of natural textile materials [27]. White-rot fungi, which have lignocelluloses degrading enzymes, degrade lignins not only to use them as carbon sources but also to remove a physical barrier against cellulose utilization [28]. The degradation behaviour of natural geotextiles is even complex under different depths of soil. In a field study [29], reduction in tensile strength of coir geotextiles with time was observed due to the action of micro organisms and the biodegradation was found to be more pronounced up to a depth of 75cm of soil.

### III. TREATMENT METHODS

The significant factor which hinders the high performance of LCFs in industrial applications is that they are mechanically weak and are highly susceptible to chemical and biological degradations. The free hydroxyl and other oxygen-containing groups of the LCFs exhibit a tendency to attract water molecules through hydrogen-bond formation causing the fibres to swell. As a result, the cellulose molecules are exposed to microbial attacks, which degrade the cellulose and cause strength loss. Exposure to chemical environment similarly results in loss of tensile strength because of

hydrolysis, oxidation or dehydration reactions. Basic principle underlying fibre treatment techniques is the blocking of free hydroxyl groups in fibre components. This ultimately minimises microbial degradation and increases long term mechanical strength by making the LCFs less hydrophilic [25].

#### A. Alkali treatment and Alkali-steam treatment

Natural fibres can be subjected to alkali treatment (commonly, aqueous NaOH) in order to modify the surface of fibres leading to increased wettability and interfacial strength of fibres with polymer resin [30]. NaOH changes the orientation of highly packed crystalline cellulose order forming an amorphous region. This provides more access to penetration of chemicals. [31].

Treatment of coir fibres with 5% aqueous NaOH at curing periods of 72 h to 96 h resulted in increased wettability and dispersability of fibres in polymer matrix. An increase of 15% in tensile strength was observed. Higher curing periods showed gradual decrease in strength [30]. Since alkali can dissolve and remove waxy coating from fibre surface and make it rough, excessive concentration of alkali can possibly damage the fibre.

Alkali treatment (0.5 – 18%) at ambient and elevated temperature ( $90\pm 2^{\circ}\text{C}$ ) was attempted on jute fibres also [32]. Curing duration varied from 30 min to 24 h. Concentrations beyond 4% NaOH resulted in reduction of tensile strength of fibres at ambient temperature. At elevated temperature, damage occurs in native cellulose structure, leading to thermal degradation and lesser crystallinity index. Similar results were observed in alkali-steam treated fibres also. Alkali treated fibres were also subjected to steam explosion at  $103\pm 2$  kPa gauge pressure and  $125\pm 2^{\circ}\text{C}$  for 30 - 90 min followed by sudden release of steam. Roughest fibre surfaces could be obtained by this process.

Steam treatment of fibres without any pretreatment does not result in any significant modification of the fibre. Steam treatment on flax fibres at temperature varying from  $160^{\circ}\text{C}$  to  $220^{\circ}\text{C}$  for various durations of time proved that the modification of fibre is marginal [33]. Steam treatment is generally adopted for enhancing the digestibility of lignocellulosic biomass.

#### B. Enzyme treatment

LCFs undergo microbial degradation mainly due to the action of enzymes produced by fungi. Fungal pretreatments are generally adopted to produce sugars from lignocellulosic biomass. Enzymes are capable of removing pectin and hemicelluloses from plant fibres thus improving its surface and thermal properties. [33]. Treatment of flax fibres using enzyme, laccase in acidic condition at  $23^{\circ}\text{C}$ ,  $36^{\circ}\text{C}$  and  $50^{\circ}\text{C}$  for durations 1 h and 2 h in an aerobic environment resulted in increased wettability and thermal stability of fibres. However, the treatment did not significantly alter crystallinity and

hydrophilicity of the fibre [34]. Lignin selective enzymes attack lignin in fibre and substantially degrade it [35]. Enzymatic treatments are generally considered to be expensive and choice of enzyme is highly specific based on fibre composition.

#### C. *Transesterification using vegetable oils*

Reactions of cellulose with vegetable oils can produce hydrophobic fibre surfaces. To achieve resilient hydrophobic surfaces, covalent bonded structures are most desirable. Transesterification reaction between triglycerides develops covalent bonded hydrophobic long acyl chains to the cellulose, leading to cellulosic fibres with hydrophobic surfaces. Four vegetable oils such as coconut oil, olive oil, rape seed oil and soy bean oil were delivered as solution as well as emulsion to cotton fabrics to achieve hydrophobicity [36]. Oils with higher unsaturation in the fatty acids, applied in solution form gave promising results, which supports the above statement. Chemical modification of jute fibres and geotextiles without compromising flexibility could be achieved by partial transesterification of some of the hydroxyl groups using reagents such as neem oil and plant tannin. This treatment could increase fibre crystallinity leading to higher tensile strength and better degradation resistance [24]. It can be understood from various case studies that higher unsaturation in the fatty acids leads to achievement of highly crosslinked network, resulting in more hydrophobic surfaces.

#### D. *UV Grafting with monomers*

Application of UV monomers involving physico-chemical process in fibre enhancement is a relatively new concept. Limited research has been reported in this area. Alkali pretreated natural fibres modified using monomers when subjected to UV ageing has been found to have lasting effects on the mechanical behaviour of coir fibres such as tensile strength, elongation at break and Young's modulus. The commonly adopted monomers include 2-Hydroxyethyl methacrylate (HEMA), acrylamide monomer (AA) and ethylene dimethyl acrylate (EMA) Removal of surface imperfections and penetration of monomer into pores of the fibre results in the formation of a mechanically interlocking coating which attributes to the increased fibre strength [37, 38,39].

#### E. *Physical Coatings*

In this technique, the fibre surface is modified by physical means, mostly using synthetic polymers or resins. The life of natural fibres like coir can be checked by coating with water repellent substance. This will physically prevent the entry of moisture into fibre making it more durable. Bitumen coated jute geotextiles used in bank protection works on the Hooghly estuary could defer degradation by about 3 – 4 years [40]. While reducing the hydrophilicity, bitumen affects the flexibility and drapability of geotextiles [24]. Moisture absorption studies were conducted on coir fibre coated using

bitumen, wood varnish and kerosene with various curing periods. At the end of 365 days, kerosene and bitumen coated fibres exhibited reduced moisture intake while varnish coated fibres did not give any significant result [10]. Coating with latex forms a protective coating on the surface of fibre, making it water repellent, thus reducing moisture absorption [12]. Thermosetting polyester coating improves the durability, strength, stiffness and decreases the water absorption of coir fibres without restricting maximum deformation. Although coatings using synthetic polymers and natural resins reduce water absorption, they result in poor wettability & lead to debonding of coating from fibre with age. From different studies [26, 30], it can be concluded that the effect of the coatings is highly dependent on pre-treatment techniques adopted.

#### F. *Treatment using specific chemicals*

Certain specific chemicals can be applied to alter the surface as well as interior of natural fibres. Stearic acid in ethyl alcohol solution is used to modify the fibre surfaces by removal of non-crystalline (pectin, wax oil covering materials, etc.) constituents from the fibre structure. Application of potassium permanganate in acetone solution to natural fibres enhances chemical interlocking at the interface and provides better adhesion with the matrix. Triazine treatment is also used for surface modification of the natural fibres. A triazine derivative has multifunctional groups in its structure. This modification provides crosslinking between the cellulose through hydrogen bond and develops strong adhesion at the interface. Treatment with isocyanate imparts higher moisture resistance properties to the fibre and provides better bonding with the matrix to enhance composite properties [31]. Silane treatment is capable of improving moisture resistance in natural fibres for different water activity ranges due to the removal of cementing materials which occurs during the chemical treatments. Treatment of natural fibres using styrene improves barrier effect to water and also favour adhesion between fibres and unsaturated polyester resins [41].

#### G. *Natural Anti-microbial Finishing*

A vast range of anti-microbial agents in nature such as chitosan, aloe vera, tea tree oil, clove oil and extracts of neem, eucalyptus and thulasi have been found to successfully impart microbial resistance in natural and synthetic fabrics. Various mechanisms of different classes of anti-microbial compounds from plants follow diverse mechanisms such as protein binding, membrane disruption and complex formation with cell wall [42]. Anti-microbial finishing of polyester/cotton blend fabrics using glycol as crosslinking agent showed that 5% neem seed oil could provide anti-bacterial activity against gram positive and gram negative bacteria [43]. Application of water-soluble chitosan derivative to cotton fabric in presence of a suitable fiber-reactive group showed 100% of bacterial reduction against *S. aureus* [44]. The composition of all natural fibres exhibits nearly a similar pattern. Hence, it is possible that the application of these anti-microbial agents can be extended to geotextiles also.

#### IV. CONCLUSION

Applications of natural fibres in engineering projects are manifold. They extend from light weight composites to ground engineering applications. The renewed interest in the natural fibres has resulted in the development of large number of modification techniques to bring them at par and even superior to synthetic fibres. From the wide range of fibre modification techniques available in practice, suitable modification and design based on the function to be performed by the fibre can be chosen to yield optimum result.

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#### References

- [1] J. Khedari, S. Charoenvai, and J. Hirunlabh, "New insulating particleboards from durian peel and coconut coir", *Building and Environment*, Vol. 38, pp. 245–249, 2003.
- [2] R.Sarsby, R.W. Ali, M. R. Alurs De, J.H. Khaffaf, and McDougall, "The use of natural and low cost soil reinforcement", *Proceeding of International Conference on Nonwoven*, The Textile Institute, New Delhi, December, pp. 297–310, 1992.
- [3] S. Kalia, B.S. Kaith and I. Kaur, "Pretreatments of Natural Fibers and their Application as Reinforcing Material in Polymer Composites—A Review", *Polymer Engineering and Science*, pp. 1253 – 1272, 2009.
- [4] R. W. Sarsby, "Use of 'Limited Life Geotextiles' (LLGs) for basal reinforcement of embankments built on soft clay", *Geotextiles and Geomembranes*, Vol. 25, pp. 302–310, 2007.
- [5] C.M. Hansen and A. Bjorkman, "The Ultrastructure of Wood from a Solubility Parameter Point of View", *Holzforschung*, Vol. 52(4) , pp. 335, Jan 1998.
- [6] M.Z. Rong, M.Q. Zhang, Y. Liu, G.C. Yang, and H.M. Zeng, "The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy", *Composites Science and Technology* Vol. 61(10) , pp. 1437–1447, August 2001
- [7] Z.N. Azwa, B.F. Yousif , A.C. Manalo, W. Karunasena, "A review on the degradability of polymeric composites based on natural fibres", *Materials and Design*, Vol. 47, pp. 424–442, 2013.
- [8] D. Chandramohan & .K. Marimuthu, "A Review on Natural Fibres", *International Journal of Research and Reviews in Applied Sciences*, Vol.8 (2), August 2011
- [9] G. L. Sivakumar Babu and A. K. Vasudevan, "Strength and Stiffness Response of Coir Fiber-Reinforced Tropical Soil", *Journal of Materials in Civil Engineering*, Vol 20(9), pp. 571- 577, September 2008.
- [10] H.N. Ramesh, K.V. Manoj Krishna and Meena, "Performance of coated coir fibers on the compressive strength behavior of reinforced soil", *International Journal of Earth Sciences and Engineering*, Vol. 4(6) SPL, pp. 26-29, October 2011.
- [11] D.U. Shah, "Characterisation and optimization of plant fibre composites for structural applications", Pd. D Thesis, University of Nottingham, August 2013
- [12] S. Chandrakaran and P.K. Sreela, "Durability Studies on Coir Geotextiles", *Geosynthetics*, Long Beach, California, April 2013.
- [13] K. R. Lekha and V. Kavitha, "Coir geotextile reinforced clay dykes for drainage of low-lying areas", *Geotextiles and Geomembranes*, Vol. 24 (1), pp. 38–51, 2006.
- [14] G.V. Rao, K. Balan, "Coir Geotextiles—Emerging Trends", *The Kerala State Coir Corporation Ltd., Alappuzha, Kerala, India, 2000.*
- [15] S. Vishnudas, H. H. G. Savenije, P. Van der Zaag, K. R. Anil, and K. Balan , "The protective and attractive covering of a vegetated embankment using coir geotextiles", *Hydrology and Earth Sciences*, Vol. 10, pp. 565–574, 2006.
- [16] T. S. Ramanatha Ayyar, C.G. Ramachandran Nair and N. Balakrishnan Nair, "Comprehensive Reference Book on Coir Geotextiles", Centre for Development of Coir Technology (Publishers), Kerala, India, 2002.
- [17] B. C. Chattopadhyay and S. Chakravarty, "Containment of Sulfate Pollution in Soil by Natural Geotextile from Jute", *Journal of Materials in Civil Engineering*, Vol. 21, pp 128-132, 2009.
- [18] G. Mukkulath and S. G. Thampi, "Biodegradation of Coir Geotextiles Attached Media in Aerobic Biological Wastewater Treatment", *Journal of Bioremediation & Biodegradation*, Vol. 3(11), 2012.
- [19] N.W. Manthey, F. Cardona, T. Aravinthan, H. Wang and T. Cooney, "Natural fibre composites with Epoxidised Vegetable Oil (EVO) resins : A review", *Southern Region Engineering Conference*, University of Southern Queensland, November 2010.
- [20] G. Basu , A.N. Roy, S.K. Bhattacharyya and S.K. Ghosh, "Construction of unpaved rural road using jute–synthetic blended woven geotextile – A case study", *Geotextiles and Geomembranes*, Vol. 27, pp 506–512, 2009.
- [21] A. Mwasha, "Using environmentally friendly geotextiles for soil reinforcement:A parametric study, *Materials and Design*", Vol. 30, pp 1798–1803, 2009.
- [22] E. A. Subaida, S. Chandrakaran and N Sankar, "Experimental investigations on tensile and pullout behaviour of woven coir geotextiles", *Geotextiles and Geomembranes*, Vol. 26, pp 384 – 392, 2008.
- [23] J Holbery and D Houston, "Natural-fiber-reinforced polymer composites in automotive applications", *The Journal of The Minerals, Metals & Materials Society* , pp 80-88, 2006.
- [24] P. Saha , D. Roy, S. Manna, B. Adhikari, R. Sen and S. Roy, "Durability of transesterified jute geotextiles", *Geotextiles and Geomembranes*, Vol. 35, pp 69 – 75, 2012.
- [25] P. Saha , S. Manna, R. Sen, D. Roy, B. Adhikari, Durability of lignocellulosic fibres treated with vegetable oil - phenolic resin, *Carbohydrate Polymers*, Vol. 87, pp. 1628 – 1636, 2012.
- [26] K. Rajagopal and S. Ramakrishna, "Coir geotextiles as separation and filtration layer for low intensity road bases", *Proceedings of Indian Geotechnical Conference IGC*, Guntur, India, 2009.
- [27] S.N. Basu, A.P. Bhattacharyya, and R.G. Bose, "A multiple culture technique for testing rot resistance, particularly suited to jute materials", *Journal of Textile Institute*, pp. 466-480, 1950.
- [28] P. Kanmani, P. Karuppasamy, C. Pothiraj, and V. Arul, "Studies on lignocellulose biodegradation of coir waste in solid state fermentation using *Phanerocheate chrysosporium* and *Rhizopus stolonifer*", *African Journal of Biotechnology*, Vol. 8, pp. 6880 – 6887, 2009.
- [29] S. Joy, K. Balan and P.K. Jayasree, "Biodegradation of coir geotextile in tropical climatic conditions", *Proceedings of Indian Geotechnical Conference (Paper No. J-341)*, pp 604 – 606, 2011.
- [30] S.V. Prasad, C. Pavithran and P.K. Rotagi, "Alkali treatment of coir fibres for coir-polyester composites", *Journal of Materials Science*, Vol. (18), pp 1443-1454, 1983.
- [31] M.M. Kabir, H. Wang, K.T. Lau and F. Cardona, "Chemical treatments on plant-based natural fibre reinforced polymer composites: An overview", *Composites: Part B*, Vol. 43, pp. 2883–2892, 2012.
- [32] P. Saha, S. Manna, S.R. Chowdhury and R. Sen, "Enhancement of tensile strength of lignocellulosic jute fibers by alkali-steam treatment", *Bioresource Technology*, Vol. 101, pp 3182 – 3187, 2010.
- [33] M. George, P.G. Mussone and D.C. Bressler, "Surface and thermal characterization of natural fibres treated with enzymes", *Industrial Crops and Products*, Vol. 53, 365– 373, 2014.
- [34] Y. Cao, F. Chan, Y. Chui and H. Xiao, "Properties of modified flax fibres", *BioResources*, Vol. 7(3), pp. 4109 – 4121, 2012.
- [35] L. Otjen, R.A. and Blanchette, "Selective delignification of Aspen wood blocks invitro by 3 white Rot Basidiomycetes, *Appl Environ Microbiology*", Vol. 50(3), pp. 568-572, 1985.

- [36] T.A. Dankovich and Y. Hsieh, "Surface Modification of cellulose with plant triglycerides for hydrophobicity", *Cellulose*, Vol. 14, pp 469 – 480, 2007.
- [37] M.A. Khan, M.S. Siraj, M.M. Rahman, L.T. Drzal, "Improvement of mechanical properties of coir fiber (*Cocos nucifera*) with 2-hydroxyethyl methacrylate(HEMA) by photo curing", *Polymer Plastics Technology and Engineering*, Vol. 42(2), pp. 253-267, 2003.
- [38] M.M. Hassan, M.R. Islam, M.A. Khan, " Effect of additives on the improvement mechanical and degradable properties of photografted jute yarn with acrylamide", *Journal of Polymers and the Environment*, Vol. 10, No. 4, pp. 139 – 145, 2002.
- [39] M.M. Rahman and M.A. Khan, "Surface treatment of coir (*Cocos nucifera*) fibers and its influence on the fibers' physico-mechanical properties", *Composites Science and Technology*, Vol.(67), pp. 2369 – 2376, 2007.
- [40] T. Sanyal and K. Chakraborty, "Application of bitumen - coated jute geotextile in bank-protection works in Hoogly estuary", *Geotextiles and Geomembranes* Vol. 13, pp 127-132, 1994.
- [41] S. Alix, E. Philippe, A. Bessadok, L. Lebrun, C. Morvan and S. Marais, "Effect of chemical treatments on water sorption and mechanical properties of flax fibres", *Bioresource Technology* Vol. 100, pp. 4742–4749, 2009.
- [42] M. Joshi, S.W. Ali and R. Purwar, "Ecofriendly antimicrobial finishing of textiles using bioactive agents based on natural products", *Indian Journal of Fibre & Textile Research*, Vol. 34, pp. 295 – 304, September 2009.
- [43] M. Joshi, S.W. Ali and R. Rajendran "Antibacterial finishing of polyester/cotton blend fabrics using neem (*Azadirachta indica*): a natural bioactive agent", *Journal of Applied Polymer Science*, Vol.106, pp. 793 – 800, 2007.
- [44] S.H. Lim and S. M. Hudson, "Application of a fiber-reactive chitosan derivative to cotton fabric as an antimicrobial textile finish", *Carbohydrate Polymers*, Vol. 56, pp. 227 – 234, 2004

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