論文

천연섬유보강 복합재료의 최근 연구 개발

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Recent Developments in Natural Fiber Reinforced Composites

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ABSTRACT

Natural fiber reinforced composites are emerging as low-cost, lightweight, recyclable, and eco-friendly materials. These are biodegradable and non-abrasive. Due to eco-friendly and biodegradable characteristics of natural fibers, they are being considered as potential candidates to replace the conventional fibers.The chemical, mechanical, and physical properties of natural fibers have distinct features depending upon the cellulose content of the fibers which varies from fiber to fiber. The mechanical properties of composites are influenced mainly by the adhesion between matrix and fibers. Several chemical and physical modification methods of fiber surface were incorporated to improve the fiber-matrix adhesion resulting in the enhancement of mechanical properties of the composites. This paper outlines the works reported on natural fiber reinforced composites with special reference to the type of fibers, polymer matrix, processing techniques, treatment of fibers, and fiber-matrix interface.

초 록

천연섬유복합재료는 저비용, 경량, 재생성, 친환경적인 재료로 최근 제조되고 있다. 또한 이들 재료는 생체분해성과 비연마 특성을 갖고 있다. 천연섬유의 친환경적이고 생체분해성으로 인해 천연섬유복합재료는 기존의 섬유를 대체할 잠재적인 대체재로 관심을 받고 있다. 천연섬유의 화학적, 기계적, 물리적 특성은 다양한 섬유의 셀룰로스양에 따라 명확한 특징이 구분되며, 이러한 복합재료의 기계적인 물성치는 기지재와 섬유간의 접착에 의해 주로 영향을 받고 있다. 천연섬유표면의 여러 화학적인 물리적인 개질방법은 섬유와 기지의 접착력 향상에 영향을 주어 결국 복합재료의 기계적인 물성치를 향상시킬 수 있다. 본 논문은 최근 개발되고 있는 천연섬유복합재료의 섬유종류, 고분자기지, 제조기술, 섬유의 처리, 섬유-기지간 계면등에 관한 최근의 연구결과들을 정리하여 소개한 것이다.

Key Words : 천연섬유(Natural Fibers), 친환경재료(Echo-friendly Materials), 생체분해특성(Biodegradable Characteristics), 표면개질(Surface modification), 결합제(Coupling Agent)

1. 서 론

In the recent years, considerable research and development have been expanded in natural fibers as a reinforcement in thermoplastic resinous matrix. These reinforced plastics serve as an inexpensive, biodegradable, renewable, and nontoxic alternative to conventional fiber reinforced composites. The various advantages of natural fibers over man-made fibers are low-cost, low density, competitive specific mechanicalproperties, reduced energy consumption, and biodegradability. Thermoplastic

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materials that currently dominate as matrics for natural fibers are polypropylene, polyethylene, while thermosets, such as phenolics and polyesters, are common matrics. With a view to replacing the wooden fittings, fixtures, and furniture, organic matrix and resinreinforced with natural fibers, such as jute, kenaf, sisal, coir, straw, hemp, rice husk, bamboo, etc., have been explored in the past decades.

There is an increasing demand from automotive companies for materials with sound abatement capability as well as reduced weight for fuel efficiency. Natural fibers possess excellent sound absorbing efficiency and are more shatter resistant and have better energy management characteristics than conventionalfiber reinforced composites. In automotive parts, such composites not only reduce the mass of the component but also lower the energy needed for production by 80%. Demands for natural fibers in plastic composites are forecast to grow at 15-20% annually with a growth rate of 15-20% in automotive applicationsand 50% or more in selected building applications [1].

However, certain problems associated with the use of natural fibers as reinforcement for polymers, such as tendency to form aggregates during processing, low thermal stability, low resistance to moisture,and seasonal quality variations (even between indivudual plants in the same cultivation), greatly reduced the potential of plant fibers to be used as reinforcement for polymers. The high moisture absorption of plant fibers leads to swelling and presence of voids at the interface, which results in poor mechanical properties and reduces deimensional stability. The main problem of natural fiber/polymer composites is the incompatibility between the hydrophilic natural fibers and the hydrophobic thermoplastic matrices. It necessitates the use of compatibilizers or coupling agents in order to improve the adhesion between fiber and matrix [2]. For the purpose of making engineering parts with natural fiber reinforced composites, extensive studieson the effect of different coupling agents, such as silanes, maleic anhydride grafted polypropylene (MAPP) or modification by acetylation, have been reported in the literatures .

In this paper, an attempt has been made to review the recently reported works on various aspects of natural fiber reinforcedcomposites. The modifications of fiber and matrix are discussed and recent developments of such composites are addressed.

2. Natural Fibers

2.1 Available Natural Fibers

Several types of lignocellulosic fibers have been investigated [1-25]. A comprehensive review of the cellulose-based materials in composites has appeared recently [2]. The lignocellulosic fibers that have been available so far and used in polyolefins include jute [1,13,19,20,22,25], coir [2], lyocell [4], wood [2,6,9], hemp [10,11], pine [7,14], rice husk [6,15,16], wheat straw [17], and sisal [2,18,21,24]. Before discussing the recent developments, chemical composition, mechanical properties, modifications of fibersand different types of manufacturing processes should be discussed.

2.2 Chemical Composition of Natural Fibers

The chemical composition of natural fibers varies depending upon the type of fiber. Primarily, natural fiberscontain cellulose, hemicellulose, pectin, and lignin. The presence of each constituent contributes to the overall properties of the fiber. Hemicellulose is responsible for the biodegradation, moisture absorption, and thermal degradation of the fibers as it shows least resistance whereas lignin is thermally stable but is responsible for the UV degradation. The percentage composition of each of these components varies for different fibers. Generally, the fibers contain 60–80% cellulose, 5–20% lignin, and 8-15% moisture. The chemical compositions of some natural fibers are summarized in Table 1.

2.3 Mechanical Properties of Natural Fibers

The properties of natural fiber reinforced composites depend on a number of parameters such as volume fraction of the fibers, fiber aspect ratio, fiber–matrix adhesion, stress transfer at the interface, and orientation. The tensile strength is more sensitive to the matrix properties, whereas the modulus is dependent on the fiber properties. To improve the tensile strength, a strong interface, low stress concentration, and proper fiber orientation are required whereas fiber concentration, fiber wetting in the matrix phase, and high fiber aspect ratio determine the tensile modulus. Most of the studies on natural fiber composites involve study of mechanical properties as a function of fiber content, effect of various treatments of fibers, and the use of external coupling agents. Other aspects include the prediction of modulus and strength using some well-established models for two-phase systems and comparison with experimental data. Mechanical properties of some natural fibers are presented in Table 2.

Table 1 Chemical composition of natural fibers [3]

Fiber	Cellulose (wt%)	Lignin (wt%)	Hemi-cellulose (wt%)	Pectin (wt%)	Moisture content (wt%)
Jute	61-71.5	12-13	13.6-20.4	0.4	12.6
Hemp	70.2-74.4	3.7-5.7	17.9-22.4	0.9	10
Kenaf	31-39	15-19	21.5	-	12
Flax	71	2.2	18.6-20.6	2.3	10
Ramie	68.6-76.2	0.6-0.7	13.1-16.7	1.9	8
Sisal	67-78	8-11	10.0-14.2	10	11
Coir	36-43	41-45	10-20	3-4	8
Lyocell	60	28	-	-	-

Table 2 Mechanical properties of natural fibers [3]

Fiber	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Jute	1.3-1.45	393-773	13-26.5	1.16-1.5
Hemp	-	690	-	1.6
Kenaf	-	-	-	2.7
Flax	1.5	345-1100	27	2.7-3.2
Ramie	1	400-938	61.4-128	1.2-3.8
Sisal	1.45	468-640	9.4-22.0	3-7
Coir	1.15	131-175	4-6	15-40
Lyocell	1.5	1400	36	6

Table 3 Chemical compounds for fiber surface modification and coupling agents

Fiber	Chemical compounds	Coupling agents
Wood	EVA, hydrocerol	MAHgPP [2,6,9]
Hemp	NaOH, $Na_2S_2O_3$	MAPP [10,11]
Sisal	NaOH	MA [2,18,24]
Pine	CH_3COOH	Silane [7,14]
Coir	EVA	MAHgPP [2]
Jute	-	MAHgPP [13]
Lyocell	-	MAPP [4]

2.4 Modification of Natural Fibers

Natural fiber composites present lower mechanical properties due to the low mechanical properties of fibers. In addition, their mechanical properties might be influenced by moisture content and thermal degradation of fibers as well as fiber/matrix adhesion. The quality of the fiber/matrix interface is significant for application of natural fibers as reinforcement for composites. Therefore, various physical and chemical methods are usually used to optimize this interface for enhancing the mechanical properties of composites. Physical and mechanical methods, such as stretching, calendaring, heat treatment, production of hybrid yarns, plasma treatment and electric discharge, do not change the chemical composition of the fibers, but change structural and surface properties of the fiber and thereby influence the mechanical properties. Strongly polarized natural fibers are inherently incompatible with the hydrophobic resins. Therefore, chemical methods, such as change of fiber surface tension, chemical coupling, acetylation, alkali treatment, and use of graft copolymerization of matrix are considered to improve fiber/ matrix adhesion in composites [3]. Various chemical compounds for fiber surface modification and coupling agents are shownin Table 3.

2.5 Manufacturing Processes of Natural Fiber Composites

Considerable interest has been generated in the manufacture of thermosetting and thermoplastic composites due to their unique properties, such as good fracture toughness and thermal stability [1, 5-9]. Thermosetting polymer composites are processed by simple processing techniques such as hand layup and spraying, compression molding, injection molding, and pressure bag molding operations. A few other methods such as centrifugal casting, cold press molding, continuous laminating, filament winding, pultrusion and vacuum forming are being used for composites but use of these methods for natural fiber composites is hardly reported [3]. Due to more stringent demands for recycling standards, thermoplastic polymers are substituting thermosetting polymers as matrix materials for natural fiber composites. The processing of natural fiber composites mainly involves extrusion of the ingredients at melt temperatures followed by shaping operations such as compression molding and thermoforming.

Fiber-fiber interactions as well as fiber-matrix interactions play a crucial role in determining the properties of natural fiber composites. It is observed that these fibers do not function as an effective reinforcement system due to poor adhesion at the fiber–matrix interface. Cellulose fibers also tend to aggregate and therefore the fibers do not disperse well in a hydrophobic polymer matrix and thus pose difficulties in achieving a uniform distribution of fibers in the matrix. The surface characteristics of the reinforcing fibers are important in transferring stress from the matrix to the fiber. The pretreatment of the fibers with suitable additives prior to processing leads to good dispersion and significantly improved mechanical properties of the composites.

3. Recent Developments

A natural fiber composite with an outstanding combination of properties is not a dream today. Use of proper processing techniques, fiber treatments, and compatibilizers/coupling agents can lead to composites with optimum properties for a particular application. This section is intended to report some recent developments in natural fiber composites.

Khondker *et al.*[1] have reported that the jute/PP unidirectional composites with only 20% of fiber content show a remarkable improvement in the tensile and bending properties when compared to those of the virgin PP. The improvements in the mechanical properties are broadly related to various factors, such as the wettability of resin melts into fiber bundles, interfacial adhesion, orientation, and uniform distribution of matrix-fibers and the lack of fiber attrition and attenuation during tubular braiding process.

The water absorption properties of coir, sisal and woodfibers reinforced PP composites in water at three different temperatures, 23, 50, and 70°C, were studied. A decrease in tensile properties of the composites was demonstrated, showing a great loss in mechanical properties of the water-saturated samples compared to the dry samples. However, the use of a post-industrial polypropylene with a low percentage of EVA in its composition in some cases leads to improved resistance to water absorption [2].

Goda and Cao [3] have reviewed recent studies and developments related to fully green composites. Various green composites, including short-fiber green composites, unidirectional green composites, textile and cross-ply composites, and technologies for improved use of natural fibers as well as these composites are discussed in terms of their fabrication methods, molding conditions and mechanical properties. Finally, future development trends related to fully green composites were predicted.

The hardness and elastic modulus of a cellulose fiber (lyocell)-reinforced PP composite were investigated by nano-indentation with a continuous stiffness technique.A line of indents was produced from the fiber to the matrix. There was a gradient of hardness and modulus across the interphase region. The distinct properties of the transition zone were revealed by 1–4 indents, depending on nano–indentation depth and spacing [4].

High-tenacity man-made cellulose filament yarn (rayon tire cord yarn) has been used to reinforced PP, polyethylene, high impact polystyrene (HIPS), and poly (lactic acid) (PLA). The pultrusion compounding method was developed for highly homogeneous composites. For a fiber load of 30 wt%, typical values for tensile strength, modulus, charpy unnotched, and notched impact strengths are 80 MPa, 3.5 GPa, 85 kJ/m^2, and 12 kJ/m^2, respectively. A high impact resistance level was maintained also at low temperatures where the matrix material becomes brittle. For the other matrix materials, similar reinforcing effects were observed, except for the impact behavior of HIPS, where the reinforcing fibers interfere with the impact modification of the matrix polymer. In contrast, the impact characteristics of PLA are drastically improved increasing the unnotched and notched charpy strengths by 380% and 200%, respectively [5].

The tensile and Izod impact strength properties of rice- husk flour and wood flour as the reinforcing filler and different compatibilizing agents were discussed by assessing their mechanical properties and the morphological characteristics of their fracture surfaces [6]. The tensile properties of the composites made with the twin-screw extruding system were better than those of the composites made with the single-screw extruding system, due to the improved dispersion of the filler. The tensile strength and modulus of the lignocellulosic filler–PP composite made with the twin-screw extruding system were improved in the case of the composite made without any compatibilizing agent and significantly improved in the case of the composite made with the compatibilizing agent, as compared with those made with the single-screw extruding system. The Izod impact strengths of the composites made with the two different extruding systems were almost the same, the degree of dispersion of the fillers might influence the notched impact performance, but the similar impact strength of both samples with different extruding processes might be due to the fact that impact test is not discriminating enough to reveal the difference in dispersion status of the composites.

The mechanical properties of the CFs reinforced polyethylene composites increased with increasing the average fiber length. The composite materials prepared using both matrices and cellulose fibers treated with γ-methacryloxypropyltrimethoxy silane (MPS) and γ-mercaptoproyltrimethoxy silane (MRPS) displayed good mechanical performances. Figure1 shows a schematic representation of the different possible reactions occurring in presence of MPS and MRPS silanes which are promoted by radical grafting reaction between the –C=C unsaturated natural rubbers and terminal acrylic moieties of MPS or –SH groups of MRPS. On the other hand, with hexadecyltrimethoxy-silanes (HDS) bearing merely aliphatic chain only, a modest enhancement on composite properties was observed [7].

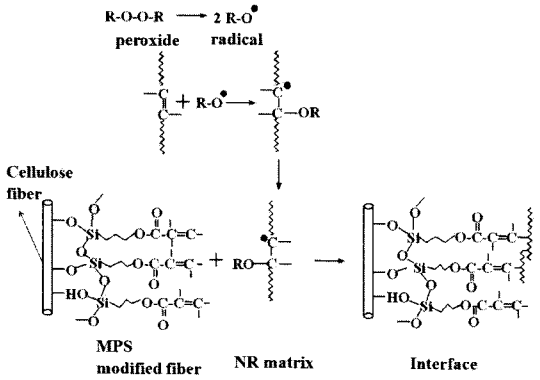

Fig. 1 A schematic of the interfacial zone in natural rubbers [7].

Qiu *et al.* [8] have reported that PP with higher molecular weight revealed stronger interfacial interaction with cellulose fibers in the composites, compared with the lower molecular weight PP; the composites derived from higher molecular weight of PP exhibited stronger tensile strength at the same cellulose content.

Tensile and flexural tests were performed on the foamed composites to investigate the dependence of these properties on the density of foamed composites. The properties of foamed composites were compared with those of non-foamed composites. Application of MAH–PP has improved the physico-mechanical properties up to 80%. Chemical foaming agents have also an effect on surface roughness of the composites which decreased surface roughness of the foamed composites compared to the non-foamed composites. Water absorption and thickness swelling of the composites were also investigated. The density of microfoamed hard wood fiber–PP composites reduced around 30% by using an exothermic chemical foaming agent. Optical microscopy showed that the cells were round and cell sizes were affected by chemical foaming agents [9].

The composites of isotactic PP with hemp fibers (*Cannabis sativa*), functionalized by means of melt grafting reactions with glycidyl methacrylate (GMA), were prepared by batch mixing. The modification of fibers (hemp–GMA) and polyolefin matrix (PP-g-GMA), as well as the addition of various compatibilizers (PP-g-GMA, SEBS, SEBS-g-GMA), were carried out to improve the fiber–matrix interactions. All composites displayed higher tensile modulus (~2.9 GPa) and lower elongation at break as compared to plain PP; compatibilization with PP-g-GMA (10 phr) resulted in an increased stiffness of the composites as a consequence of an improved fiber–matrix interfacial adhesion [10].

Pickering *et al.* [11] investigated the optimization of hempfiber reinforced PP composites. The optimum growing period was found to be 114 days, producing fibers with an average tensile strength of 857MPa and a Young's modulus of 58 GPa. The strongest composite consisted of PP with 40wt% fiber and 3wt% MAPP, and had a tensile strength of 47.2 MPa, and a Young's modulus of 4.88 GPa.

A pultrusion method as shown in Figure2 was developed for fabricating green composites composed of PLA (Poly lactic acid) or PBS (Poly Butylene Succinate) resin as a matrix and kenaf fibers as a reinforcement. The tensile properties at different temperatures were evaluated. It was found that the tensile strengths and Young's moduli of PLA/kenaf and PBS/kenaf composites were larger than those of both resins alone at different temperatures. This result shows the reinforcement effect of PLA and PBS by kenaf fibers [12].

Doan *et al.* [13] investigated the effect of maleic anhydride grafted PP (MAPP) coupling agents on the properties of jute fiber/PP composites. The addition of 2wt% MAPP to PPmatrices improved the adhesion strength with jute fibers and the mechanical properties of composites.

Girones *et al.* [14] studied the PP-based composites, reinforced with surface modified pine fibers. Tensile modulus increased only by 12% after incorporation of untreated fibers to PP matrix. Treatment with silane led to a significant rise (about 60% compared with that of unfilled matrix) in tensile modulus. A higher effect was noted for MRPS, followed by MPS, HDS, and γ-aminopropyltrimethoxysilane (AMPS). Flexural modulus was amplified by 130% with fiber addition and modestly enhanced after silane treatment compared with that of untreated fibers, flexural modulus increased by 6, 5, 20, and 8% in the presence of MPS, HDS, AMPS, and MRPS, respectively.

Yang *et al.* [15] prepared a particle-reinforced composite by rice-husk flour as the reinforcing filler and PP as the thermoplastic polymer matrix. Its mechanical and morphological properties were examined as a function of the amount of compatibilizing agent used. In the sample preparation, four levels of filler loading (10, 20, 30, and 40 wt%) and three levels of compatibilizing agent content (1, 3,and 5 wt%) were used. In the tensile test, six test temperatures (-30, 0, 20, 50, 80, and 110^{0}C) and five crosshead speeds (2, 10, 100, 500, and 1500 mm/min) were used. The tensile strengths of the composites decreased as the filler loading increased, but the tensile properties were significantly improved with the addition of the compatibilizing agent. Both the notched and the unnotched Izod impact strengths were almost the same with the addition of compatibilizing agent.

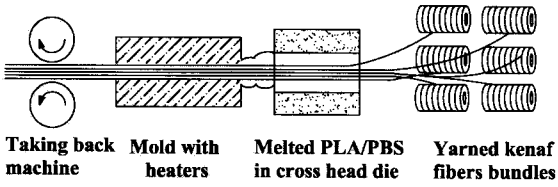

Fig. 2 Schematic view of pultrusion molding [12].

Kim *et al.*[16] investigated the effect on thermal properties of the addition of two different compatibilizing agents, maleic anhydride grafted polypropylene (MAPP) and MA-graftedpolyethylene (MAPE), to bio-flour-filled, PP, and low density polyethylene (LDPE) composites. The effect of two different types of MAPE polymer, MA-grafted high-density polyethylene (HDPE-MA) and MA-grafted linear LDPE was also examined. With increasing MAPP and MAPE content, the thermal stability, storage modulus and loss modulus wereslightly increased. The thermal stability of MAPE-treated composites was not significantly affected by the two different MAPE polymers. The melting temperature (*Tm*) of the composites was not significantly changed but the crystallinity (*Xc*) of MAPP and MAPE-treated composites was slightly increased with increasing MAPP and MAPE content. This enhancement of thermal stability and properties could be attributed to an improvement in the interfacial adhesion and compatibility between the rice husk flour (RHF) and the matrix due to the treatment of compatibilizing agent.

Panthapulakka *et al.* [17] studied the potential of wheat straw fibers prepared by mechanical and chemical processes as reinforcing additives for thermoplastics. Fibers prepared by mechanical and chemical processes were characterized with respect to their chemical composition, morphology, and physical, mechanical, and thermal properties. Composites of PP filled with 30% wheat straw fibers were prepared and their mechanical properties were also evaluated. The fibers prepared by chemical process exhibited better mechanical, physical, and thermal properties. Wheat straw fiber reinforced PP composites exhibited significantly enhanced properties compared to virgin PP. However, the strength properties of the composites were less for chemically prepared fiber filled composites. This was due to the poor dispersion of the fibers under the processing conditions used. These results indicate that wheat straw fibers can be used as potential reinforcing materials for making thermoplastic composites.

Joseph *et al.* [18] prepared sisal fiber reinforced PP composites by melt-mixing and solution-mixing methods. The methods enhanced the tensile properties of the composites. The effect of fiber content and chemical treatments on the thermal properties of sisal/PP composites was also evaluated. It was found that treated fiber composites showed superior properties compared to the untreated system. DSC measurements exhibited an increase in the crystallization temperature and crystallinity, upon the addition of fibers to the PP matrix. This is attributed to the nucleating effects of the fiber surfaces, resulting in the formation of transcrystalline regions. On increasing the fiber content, the melting peak of the PP component was shifted to higher temperatures suggesting a constrained melting.

Kazuto *et al.* [19] proposed nonwoven stacking method in order to develop the green composites with high strength and high stiffness. Laminated jute plain woven fabrics with PLA non-woven fabrics were molded as shown in Figure 3 and the influence of amount of reinforced fiber and molding temperature on the impregnation and the specific properties of the composites were discussed. Tensile strength of jute fiber was drastically degraded about 50% by high temperature due to thermal decomposition of cellulose. However, higher fiber fraction caused poor impregnation. In the case of specimens with 50 and 60vf%, due to the high fiber volume fraction ratio, impregnation was not enough to strengthen the specimen property.

Yoldas *et al.* [20] investigated the effect of oligomeric siloxane treatment of jute fabrics on mechanical properties of jute epoxy and jute polyester composites. To improve the adhesion between jute fabric and thermoset, alkali treated jute fibers were treated with oligomeric siloxane. It may be pointed out that oligomeric siloxane treatment resulted in an increase in tensile strength as well as flexuralstrength. Besides, from ILSS results, one can note that the presence of an oligomeric siloxane leads to increasing ILSS of jute/epoxy and jute/polyester composites, which can be related to the effect of improved interfacial adhesion between jute fiber and polymer matrix. The microscopic investigation of the fractured surfaces of composites revealed enhanced bonding between the matrix and the fiber.

Athijayamani *et al.* [21] investigated the effect of moisture absorption on mechanical properties of short roselle and sisal fiber-reinforced hybrid polyester composite and compared with the composites containing the dried fibers. Increasing the fiber content and length at dry condition, the tensile and the flexural strength increased. At wet condition, the tensile and flexural strength have a high-level reduction. The impact strength was reduced with the fiber content and length at dryand wet conditions.

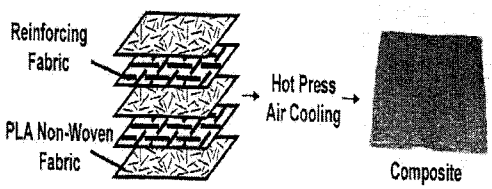

Fig. 3 Schematic view of molding process [19].

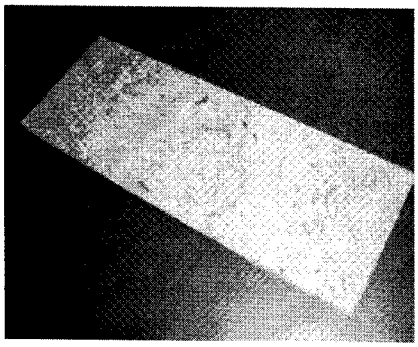

Fig. 4 The coir/rubber composite board [23].

Exposure to moisture causeda significant drop in the mechanical properties due to the degradation of the fiber matrix interface. A relationship between experimental and predicted (regression model) values wasdetermined to be strong by the high R2 values obtained. This means that agood linear relationship was expected. The statistical (regression) model presented showed a good potential to model the mechanical properties of roselle and sisal fibers hybrid polyester composites.

Liu *et al.*[22] investigated the effect of fiber surface modification on characteristics of jute fiber and mechanical properties of biocomposites. Surface modification can remove a certain amount of hemicellulose, lignin and pectin covering the external surface of the cell wall of the fiber, destructing the mesh structure and splitting the fibers into finer filaments. The main defects of lignocellulosic fiber as reinforcing materials, such as high moisture absorption, poor wettability,and incompatibility with hydrophobic polymer, all can be improved by surface modification. Regarding the mechanical properties of biocomposites, it was observed that with the increase of fibre content from 0 to 20 wt.%, the mechanical strength or modulus were all gradually increased, and with 30 wt.% fibre content they were decreased or nearly remain constant, however the breaking elongation were evidently decreased than pure PBS film. The experimental results showed that the mechanical strength or modulus of biocomposites exits an optimum value at certain fibre content, which was 20 wt.% in this study. Surface modification by alkali or coupling agent both improved the mechanical properties of biocomposites. It was because that surface modification can improve the compatibility between jute fibre and PBS, leading to less microvoids and fibre–PBS debondings in the interphase region. And the stronger fibre–matrix interface can lead to lowering of the critical fibre length for effective stress transfer.

Wang and Huang [23] analyzed thebrown coir fibre from the Hainan province of China. Composites were fabricated by using coir fibre as the reinforcement and the rubber as matrix. The coir/rubber composite with the fibre volume fraction of 60% was fabricated by using the heat press technique. The tensile strength of the produced boards as shown in Figure 4 was tested. It was found that the temperature during heat press process had no significant influence on the composites as far as the tensile strength was concerned. Coir fiber volume fraction of 60% would be the better choice in this investigation.

Kasama and Nitinat [24] investigated the effect of glass fiber hybridization on the physical properties of sisal-polypropylene composites. Polypropylene grafted with maleic anhydride (PP-g-MA) was used as a compatibilizer toenhance the compatibility between the fibers and polypropylene. Tensile, flexural, and impact properties of the sisal–PP composites were increased by adding the compatibilizer due to the improvement of interfacial adhesionbetween the fiber and matrix. Hybridization with glass fiber insignificantly enhanced the mechanical properties of the composites. Addition of glass fiber improved thermal stability of the PP composites. Thermal decomposition temperature of the composites increased with increasing glass fiber content. HDT of PP was considerably increased with adding sisal fibers and further improved by hybridization with glass fibers. However, incorporation of glass fibers into the sisal–PP composites did not notably change the viscosity. Hybridization with glass fibers decreased water absorption of the sisal–PP composites.

Jute/Cordenka hybrid composites produced by a pultrusion process and subsequent injection moulding were characterizedby their mechanical properties and the high potential for this material combination to achieve a balanced property profile wasdemonstrated. The consequences of a mercerisation treatment of the jute fibers are studied and SEM reveals jute fracture peculiarities on the micrometer scale. Stiffness and heat distortion temperatures (HDT) increased with increasing jute portion while strength and impact strength were diminished. A high level balanced property profile was obtained by the incorporation of 25% jute into a composite with a 25% overall fiber load. Tensile

modulus, strength, HDT, and charpy impact strength have values of 72 MPa, 3.2 GPa, 1060 C, and 79 kJ/m^2, respectively. Mercerisation of the jute fibers leads to moderate improvements inthe mechanical properties, most noteworthy an increase in tensile modulus by 6% with respect to the untreated fiber composites [25].

4. Conclusions

Natural fibers have distinct chemical, mechanical, and physical properties. The mechanical properties of composites are influenced mainly by the adhesion between matrix and fibers. Novel processing techniques such as injection and compression molding and chemical treatments such as dewaxing, bleaching, chemical grafting are developed to improve the fiber-matrixadhesion resulting in the enhancement of mechanical properties of the composites. However, the developments of novel processing and modification methods are not finished yet. Further improvements can be expected, so that it might become possible to substitute conventional fibers in composites quite generally. Up to now, the most important natural fibers are jute, flax, sisal, hemp and coir. The real challenge is to improve the eco-friendly and bio-degradable natural fibers which may replace the conventional fibers.

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