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Interfacial Hybridization of Lignocellulosic Fibers and it's Effect on Mechanical and Chemical Properties

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ABSTRACT

Recently there has been a resurgence of wood and other natural fibers composites in various industries and these composites are becoming a new generation material to replace the conventional materials. Hard wood as well as soft wood are the major source of lignocellulosic fibers. Non-wood lignocellulosic fibers are gaining increased attention due to light weight, high flexibility, moderate strength, biodegradability, renewability, and ease in their production and application in development of composites.

Improvement of lignocellulosic fibers by hybridization with nanoclay for the development of composites is a relatively new research area. Lignocellulosic fibers are hydrophilic in nature, so it becomes necessary to increase their surface roughness as well as their surface area for better adhesion with the hydrophobic polymer, which results in enhanced mechanical and chemical properties. In the present paper, the alkali treated distillery waste of lemongrass fibers were hybridized by organomodified montmorillonite (OMMT) clay to manufacture hybridized lignocellulosic nanocomposites. The magnetic stirrer has been used for better dispersion of the OMMT. Tensile strength, tensile modulus, flexural strength, flexural modulus, notched and unnotched impact properties were studied. The interfacial region were studied by SEM of the unhybridized and hybridized nanocomposites. The chemical resistance properties were studied under aqueous conditions in acetic acid, nitric acid, hydrochloric acid, sodium hydroxide, aqueous ammonia and sodium carbonate. Chemical resistance studies reveal maximum weight gain/loss with increasing clay content. Mechanical studies show maximum characteristics for the composites hybridized by 5 % OMMT, the tensile strength and tensile modulus were increased to 41% and 83% respectively, the flexural strength and flexural modulus increased to 53% and 15% respectively as compared to unhybridized fiber composites. The increase in notched and unnotched impact strength is up to 51% and 26% respectively, as compared to unhybridized fiber composites.

Keywords: Lenomgrass fibers (LGF), Unsaturated polyester resin (UPR), Hybridization, Lignocellulosic, distillery waste.

INTRODUCTION

Natural fibers have received great interest as reinforcing material for polymer-based matrices because of the environmental issues in combination with their low cost and some intrinsic interesting properties (density, shape ratio, mechanical behavior). A lot of research works have been performed all over the world on the use of wood polymer composites. According to Lucintel‘s report on the ―Natural Fibre Composites Market Trend and Forecast 2011–2016: Trend, Forecast and Opportunity Analysis‖ in 2010, the global natural fibre composites market has reached US $289.3 million in 2010, with compound annual growth rate (CAGR) of 15% from 2005. By 2016, NFCs market is expected to reach US $531.3 million with CAGR of 11 % over the next five years [1]. NFCs have experienced healthy growth in last six years. NFCs market is divided into two segments: wood fibre and non-wood fibres. Wood fibre is most used for building and construction, whereas non-wood fibres, such as flax, kenaf, hemp, were the main materials of choice for automotive.

In 21st century the development of polymer nanocomposites is rapidly emerging as a multidisciplinary research activity whose results could broaden the applications of polymers to the great benefit of many different industries. Polymer nanocomposites (PNC) represent a radical alternative to conventional filled polymers. In contrast to conventional composites, where the reinforcement is on the order of microns, PNCs are exemplified by discrete constituents on the order of a few nanometers. The value of PNC technology is not solely based on the mechanical enhancement of the neat resin nor the direct replacement of current filler or blend technology. Rather, its importance comes from providing value-added properties not present in the neat resin, without sacrificing the resin’s inherent processibility and mechanical properties, or by adding excessive weight. PNCs contain substantially less filler (1-5 vol %) and thus enabling greater retention of the inherent processibility and toughness of the neat resin. According Lachman N et al. (2012), development of PNCs, as with any multicomponent material, must simultaneously balance four interdependent areas: constituent selection, cost-effective processing, fabrication, and performance [2]. The UP-clay nanocomposites were synthesized by Kornmann et al. with intercalated polymer–clay nanocomposites formed by the insertion of one or more macromolecular layers into the clay host-galleries [3].

The incorporation of several different types of fibres into a single matrix has led to the development of hybrid biocomposites. The behavior of hybrid composites is a weighed sum of the individual components in which there is a more favorable balance between the inherent advantages and disadvantages. The term hybrid effect has been used to describe the phenomenon of an apparent synergistic improvement in the properties of a composite containing two or more types of fibre [4]. The selection of the components that make up the hybrid composite is determined by the purpose of hybridization, requirements imposed on the material or the construction being designed. The problem of selecting the type of compatible fibres and the level of their properties is of prime importance when designing and producing hybrid composites. The successful use of hybrid composites is determined by the chemical, mechanical and physical stability of the fibre / matrix system. The concept of hybrid systems for improved material or structural performance is well-known in engineering design. However, it is the inspiration from natures' own materials that is recently motivating the path towards innovative material and structural designs. Studies on natural materials show how high structural performance can be achieved with non-exotic materials through hybrid combinations assembled in optimized hybrid hierarchical configurations.

Hybrid composites can help us to achieve a better combination of properties than fiber reinforced composites. The constituent fibers in a hybrid composite can be altered in a number of ways leading to variation in its properties [5]. Natural rubber was reinforced using two hybrid biofibers namely sisal and oil palm. The stress relaxation characteristics of sisal/oil palm hybrid fiber reinforced natural rubber composites was analyzed with special reference to fiber loading and chemical modifications [6]. G. Venkatesha Prasanna et al. studied the mechanical properties and chemical resistance of alkali treated banana-palmyra fibers [7]. Chemical resistance was also significantly improved for all the chemicals except toluene and carbon tetrachloride. M. Jawaid et al. studied the chemical resistance, void content and tensile properties of oil palm EFB/Jute composites was investigated and found that the chemical resistance test that all the composites are resistant to various chemicals [8]. It was observed that marked reduction in void content of hybrid composites in different layering pattern. From the different layering pattern, the tensile properties were slightly higher for the composite having jute as skin and oil palm EFB as core material. Julien Bras et al. studied the effect of whiskers loading on tensile properties, thermal properties, moisture sorption, water vapor permeation, and soil biodegradation was studied. Significant improvement of Young's modulus and tensile strength was observed as a result of addition of whiskers to the rubber matrix especially at high whiskers' loading. Presence of bagasse whiskers resulted in an increase in moisture sorption of rubber films up to 5% whiskers loading while at higher whiskers' loading the moisture sorption tended to decrease. Barrier properties to water vapor decreased on increasing cellulose whiskers up to 7.5% whiskers loadings then increased with further increase in whiskers loading. Presence of cellulose whiskers increased the rate of degradation of rubber in soil [9]

There are three main material constituents in any composite: the matrix, the reinforcement (fiber), and the so-called interfacial region. The interfacial region is responsible for communication between the matrix and filler and is conventionally ascribed properties different from the bulk matrix because of its proximity to the surface of the filler. Shabnam Sheshmani et al. studied the nanocomposites based on polyethylene (PE), maleic anhydride grafted polyethylene (MAPE), recycled newsprint fibers, and organically modified montmorillonite (nanoclay). The results show that the addition of MAPE and nanoclay in the nanocomposite formulation significantly improved both the stability and water absorption properties. The improving effect of MAPE could be explained by the improvement in the quality of adhesion between the polymer and fibers. Nanocomposites containing 5 wt % MAPE and nanoclay exhibited minimum water absorption during the whole duration of immersion. The results of this research study show that wood–plastic composites treated with a coupling agent and nanoclay will be desirable as building materials for outdoor applications [10]. Yong X. Gan studied the effect of interface structures on the mechanical properties of fiber reinforced composite materials. For nanostructuring the interface in composite materials and structures by introducing nanoscale features such as nanopores and nanofibers. The effects of modifying matrices and nano-architecturing interfaces on the mechanical properties of nanocomposite materials are examined [11]. Mitchell. B.S formed of highly interfacial hybrid nanocomposites is described.the nanocomposites are formed by a two step, near net-shape manufacturing process that includes nanoparticles formation via high energy ball-milling followed by consolidation via hot isotactic pressing. Two types of hybrid materials are described: metal/ceramic nanocomposites, in which increased corrosion resistance and improved mechanical properties are highlighted; and polymer/ceramic nanocomposites, in which proton conductivity is increased [12] Layered silicate/glass fiber/epoxy hybrid composites were successfully prepared using a vacuum-assisted resin transfer molding (VARTM) process and study the effects of the fiber direction on the clay distribution in the hybrid composites, unidirectional glass fibers were placed in two directions: parallel and perpendicular to the resin flow direction. The study The results indicated that introducing a small amount of organoclay to the glass fiber/epoxy composites enhanced their mechanical and thermal properties, confirming the synergistic effects of glass fibers and clays in the composites [13]. Siwu Wu et al. Hybrids consisting of graphene oxide (GO) sheets and butadiene-styrene-vinyl pyridine rubber (VPR) were prepared by a co-coagulation process with different flocculants, hydrogen chloride and calcium chloride, in order to form two kinds of bonding interfaces, namely ionic bonding (HVPR) and hydrogen bonding (CaVPR) interfaces. To reveal the effects of interfacial interaction on the chain dynamics, the dielectric relaxation spectra of these hybrids have been investigated. The results show that all hybrids exhibit two distinct relaxation processes, segmental relaxation and interfacial relaxation. The dielectric strength ($\Delta\varepsilon$), the calculated fragility parameter and the effective activation enthalpy of the interfacial chains in HVPR are always higher than those in CaVPR with the same GO concentration. All the evidence indicates the stronger interfacial interactions in HVPR than in CaVPR [14].

2. MATERIAL AND METHODOLOGY

2.1 Materials*:*

2.1.1 Reinforcing Agent:

Lemongrass fibers are used as a reinforcing agent in this research work. Lemon grass belongs to *Cymbopogon* genus. *Cymbopogon* (lemongrass) is a genus of about 55 species of grasses, of which the type species is *Cymbopogon citratus* native to warm temperate and tropical regions of the world. distillery waste collected from the **Central Institute of Medicinal & Aromatic Plants (CIMAP),** Lucknow, India. Fig. 1 and Fig. 2 shows the lemongrass plant and the lemongrass fibers after steam distillation. The essential oil is extracted from the steam oil distillation of lemongrass. The essential oil extracted from lemongrass is used in making mosquito repellant and other medicinal cream. Distillery waste of the lemongrass, which is of no use after steam distillation, is retted in water bath for one month and lemongrass fibers (LGF) were extracted.

FIGURE 1: Lemongrass plant

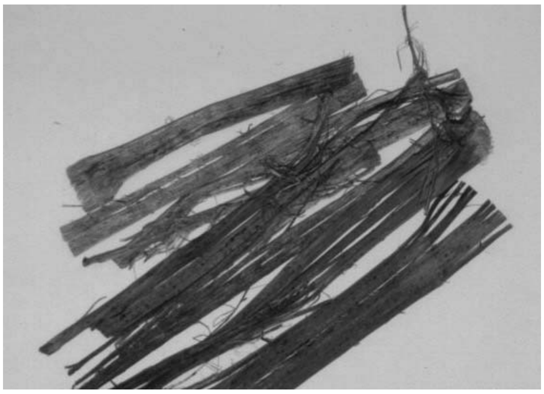

FIGURE 2: Lemongrass after steam distillation

2.1.2 Hybridizing agent

Organophilic clay plays an important role in the preparation of polymer–clay nanocomposites. The ideal organoclay should have strong interactions with the selected polymer and should improve the interfacial adhesion between the organic and inorganic phases. After inorganic cations such as Na^+ and Ca^{++} in the clay galleries are exchanged by organic cations, the clay is rendered hydrophobic and called organo-clay.

Organomodified montmorillonite (OMMT) nanoclay is used as a hybridizing agent in this experiment. OMMT is purchased from Sigma Aldrich Chjemicals Pvt. Ltd., Bangalore, India. The product number of the used nanoclay is which contains contains 0.5-5 wt. % aminopropyltriethoxysilane, 15-35 wt. % octadecylamine in the matrix of Montmorillonite clay base material. The lemon grass fibers were hybridized by OMMT. The lignocellulosic fibers are hydrophilic in nature, therefore by adding organomodified nanoclay would increase the surface area in nanoscale. This would give more interfacial bonding space, moreover adding OMMT would increase the surface roughness for better bonding and better adhesion with the hydrophobic polymer, which results in enhanced mechanical and chemical properties. In the present paper, we have hybridized the alkali modified distillery waste of lemongrass fibers by OMMT to manufacture hybridized lignocellulosic nanocomposites. The loading ratio of the OMMT is in the ratio of 0%, 1 %, 5 % and 10% wt.

2.1.3 Matrix Material:

The unsaturated polyester resin (UPR) is used as a matrix polymer. UPR is purchased from Vikram Resins and Polymers, Bangalore, India. The grade used in this research is, VRP 2121. This grade is a medium reactive, orthophthalic Acid based Unsaturated Polyester Resin designed for lamination purposes. It has low viscosity, good wetting, good mechanical properties, and is fast curing. VRP 2121 is suitable for hand lay-up, RTM, and other molding techniques.

2.1.4 Catalysts

Methyl ethyl ketone peroxide (MEKP) is used as a catalyst. It is clear transparent liquid with a slightly pungent odour. Its specific gravity is 1.11. The concentration of MEKP used in this experiment is 1 %. Catalyst is purchased from Vikram Industries, Bangalore, India.

2.1.5 Accelerators

Cobalt naphthenate (CoNAP) is used as a accelerator to promote the crosslinking reaction. In the experiments CoNAP is used in 1.5% concentration. Cobalt (II) naphthenate is a mixture of cobalt (II) derivatives of naphthenic acids. One characteristic of cobalt naphthenate and other metal carboxylates is that they readily dissociate from an ion pair into free metal and free acid. Accelerator is purchased from Vikram Industries, Bangalore, India.

2.1.6 Sodium Hydroxide for fiber surface modification

Sodium hydroxide acts as a natural fiber (NF) surface modifying agent. The sodium hydroxide (NaOH) was supplied by the Fisher Scientific, Mumbai, India. The long distillery waste fibers were soaked in 5% concentrations of NaOH solution in the water bath for 48 hour at room temperature. The ratio of the fiber and the solution used is 1:20 (w/v). After treatment, the fibers were washed and rinsed several times with distilled water. Afterwards the fibers were dried first in air and then in hot air oven at 80°C for 24 hours. The proposed reaction for this treatment is given in the following equation [1]:

$$\mathrm{Fibre - OH \ + \ NaOH \rightarrow Fibre{-}O{-}Na \ + \ H_2O} \ \mathrm{Eq[1]}$$

The main reaction is between the hydroxyl groups of cellulose and the hydrogen of the alkali. Alkali treatment of cellulosic fibers, also called mercerization, is the usual method that often used by some researches to produce a high quality fibers to reinforce polymer matrix [15-18]. All types of natural fiber, such as hemp [19], jute [20], ramie [21], henequen [22], curaua [23], flax [24], etc., have been treated with the sodium hydroxide (NaOH) before mixed together with the polymer (thermoplastics or thermosetting) to produce composites. The concentration of alkali solution used by different researchers, to treat the fibers is in the range of 0.5% up to 28%. In literature, the temperature and soaking time to treat the natural fibers in the alkali solution is in the range of 20-180°C and 15 minutes to 48 h period of time, respectively.

In order to develop composites with better mechanical properties and environmental performance, it becomes necessary to increase the hydrophobicity of the cellulose fibers and to improve the interface between matrix and fibers. Lack of good interfacial adhesion, low melting point, and poor resistance towards moisture make the use of plant cellulose fiber reinforced composites less attractive. Pretreatments of the cellulose fiber can clean the fiber surface, chemically modify the surface, stop the moisture absorption process, and increase the surface roughness [25-30].

2.2 Method

2.2.1 Mold:

The iron material is used for making sheet mold with dimensions 150 mm (L) X 150 mm (W) X 3.0 (T) mm. Polyester sheets and glass plates are used to cover the sheet mold for uniform thickness and high gloss. Silicon spray is used as a mold releasing agent for easy release of the molded sheet from the sheet mold.

2.2.2 Orientation of LGF:

The lemongrass fibers (LGF), extracted from distillery waste of lemongrass, were used in random orientation.

2.2.3 Length of LGF:

Randomly dispersed long lemongrass fibers (LGF) used, were of 150mm in length.

2.2.4 Percentage of fibers:

A 20 weight % treated fiber content of lemongrass was chosen in order to determine the effect of different concentration of OMMT for hybrid nanocomposites. The alkali concentrations used in this work was 5% by weight. Before use, LG fibers were dried at 80^0C under vacuum for 24 h.

2.2.5 Hybridizing step :-

A magnetic stirrer, also called magnetic mixer is used in this research to hybridize the lemongrass fibers surface with the OMMT. Magnetic stirrer is a laboratory device that employs a rotating magnetic field to cause a stir bar immersed in a liquid to spin very quickly, thus stirring the highly viscous liquids mixtures. The rotating field is created by a rotating magnet. The OMMT is dispersed in the UPR with the magnetic stirrer for 45 min. to 50 min. at a temp. of 70^0C and 600 rpm. Stirrer is also used to release the entrapped air from the resin before mixing the catalyst and accelerator. The accelerator and catalyst were mixed with the UPR for 10 min. at 40^0C with the help of magnetic stirrer at 600 rpm.

2.2.6 Process:

The most simple and inexpensive, hand lay-up process, is used for making the natural fiber composites. In this research work the treated and untreated fibers were cut according to the mold size and placed randomly within the mold. The OMMT is mixed with UPR in four different weight percentages, that is 0% OMMT, 1% OMMT, 5% OMMT and 10% OMMT with the magnetic stirrer for better dispersion of the nanoclay. Further the accelerator and catalyst are mixed in the above mixture of

OMMT and UPR with the magnetic stirrer. Now the compounded matrix is spread over the long and randomly placed lemongrass fibers within the mold. A transparent polyester film was kept on the top of the uncured composite. Efforts were made to remove all bubbles with the help of rolling the soft roller on the transparent polyester sheet. Lastly, a flat iron plate of thickness 5mm was kept and compressed for better packing. Thus the waste natural fibers were compressed between the polymeric layers to make a natural fiber composite (NFC). Finally, the NFC of 3 mm was left undisturbed to cure for 24 h at room temperature. The obtained composites are of the size 150 × 150 × 3 mm^3.

3. MECHANICAL TESTING, CHEMICAL RESISTANCE MEASUREMENTS AND MORPHOLOGICAL CHARACTERIZATION:

3.1 Tensile testing:

All tension testing specimens were cut into a dog-bone shape. The tensile tests were conducted following the standard of ASTM D 638 type V using Instron (Model 4301) universal testing machine with load cell of 1 kN and using crosshead speed of 50 mm/min. The test was performed until the tensile failure occurred. The results of five specimens were calculated to get the average tensile value.

3.2 Flexural testing*:*

Three points bend testing was carried out following the ASTM D790-97. The test methods are for flexural properties of unreinforced and reinforced plastics and electrical insulation materials. The similar Instron universal testing machine (Model 4301) that has been used for the tensile test was also used in this experiment for flexural testing. The applied load and the crosshead speed were specified at 1 kN and 1.3 mm/min, respectively, while the support span was 48 mm. For flexural test the samples were prepared and cut into rectangular specimens with 127 mm (L) x 12.7 mm (W) x and 3 mm (T) dimensions.

3.3 Notched and Unnotched Impact Test:

The notched and unnotched impact tests are carried out with Tinius olsen machine. The standard specimen for ASTM is 64 x 12.7 x 3.2 mm (2½ x ½ x 1/8 inch). The most common specimen thickness is 3.2 mm (0.125 inch), but the preferred thickness is 6.4 mm (0.25 inch) because it is not as likely to bend or crush. The depth under the notch of the specimen is 10.2 mm (0.4 inches).

3.4 Chemical Resistance:

Chemical resistance of polymers is a complex subject. Chemical resistance of composites depends on the matrix and reinforcements properties. The interface surface of the two phase also plays a vital role in the chemical reactions. The chemical resistance tests were done by immersion tests as per ASTM D 543-87 standards. The chemical resistance of the samples were studied in 10 % acetic acid, 10 % nitric acid, 10 % hydrochloric acid, 10 % aqueous ammonia, 10 % sodium carbonate, 10 % sodium hydroxide and water based on ASTM D543-87 standards. A specimen size of

(100 x 100 x 3) were totally immersed in the respective chemicals reagents in the petridish for fifteen days in a standard laboratory atmosphere.

3.5 Morphological Characterization:

The possibility of forming mechanical bonding at the surface is mainly dependent on the surface topology of the fibers. It is important to mention that the changes of surface topography affect the bonding between the interfacial region of the LGF and matrix UPR. Scanning electron microscopic analysis examined the surface topology of treated LGF/UPR composites and hybridized LG/OMMT/UPR nanocomposites. The sample surfaces were vacuum coated with a thin layer of platinum and gold on the surface using an Edwards S150B sputter coater (BOC Edwards, Wilmington, MA) to provide electrical conductivity and did not significantly affect the resolution. One set of sample from each type of treated and untreated fibers were examined. The tests were conducted in the Birbal Sahani Institute of Paleobotany Lucknow, India.

4. RESULTS AND DISCUSSION

4.1 Effect of OMMT Hybridization on tensile properties:

Mechanical properties of composites were strongly determined by the fiber-matrix interface. The effects of OMMT weight percentages from 0%, 1%, 5% and 10% of the LGF fibers on the tensile strength and tensile modulus were examined using the alkali treated fiber (20% weight) composites. As seen from Fig. 3 and Fig. 4, the OMMT hybridized LGF nanocomposites have improved the tensile strength and tensile modulus, as compared with the unhybridized (0% OMMT) LGF nanocomposites. By hybridizing 1% and 5% OMMT to the LGF composites, the tensile strength increases by 35% and 41%, as compared to the unhybridized (0% OMMT) LGF composites. With further increase in the OMMT weight percentage from 5 to 10, there is a decrease in the tensile strength by 17% as compared to the 5% OMMT nanocomposites. Similarly the by hybridizing 1% and 5% OMMT to the LGF composites, the tensile modulus increases by 50% and 83% respectively, as compared to the unhybridized (0% OMMT) LGF composites. The increase in the tensile properties is an indication that surface modification promoted good wettability and better fiber-matrix adhesion, allowing efficient stress transfer between the matrix and the fibers. This could be due to the increase in surface roughness for better adhesion between the hydrophilic lignocellulosic fibers the hydrophobic polymer surface. The hybridization of the fibers with OMMT could have increased the surface area of the lignocellulosic LG fibers to form better bonding between polymer and the hybridized LG fibers. Further increasing the OMMT to 10% decreases the tensile modulus by 16% as compared to the 5% OMMT nanocomposites.

Similar study was done by Farida Bensadoun et al. on the hybrid nanocomposites made from soy-based unsaturated polyester resin/glass fiber and flax fibers and observed to improve mechanical and flammability properties of reinforced composites by introducing nanoclay particles [31].

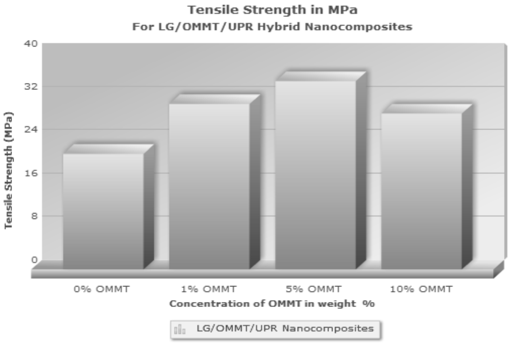

FIGURE 3: Effect of Hybridization on Tensile Strength

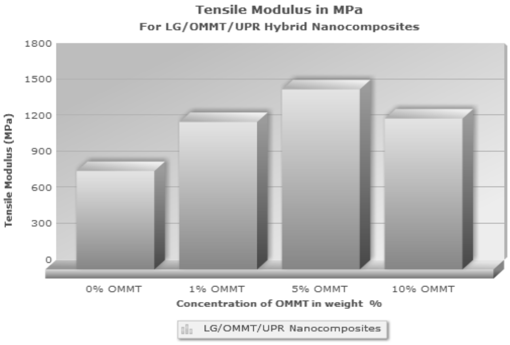

FIGURE 4: Effect of Hybridization on Tensile Modulus

4.2 Effect of OMMT Hybridization on flexural properties:

Flexural properties pertain to the resistance of material under the bending mode. The flexural properties of LGF/OMMT/UPR hybrid nanocomposites are illustrated in Fig. 5. The trend of histogram of flexural strength shows that the strength increases with increasing the weight percentage of the OMMT in the hybridized composites from 1% to 5% by 43% and 53% respectively as compared to the unhybridized composites, further increasing the OMMT percentage to 10% the flexural strength decreases by 5% as compared to the 5% OMMT hybrid composites. The Fig. 6 illustrates that the hybridization of 1% and 5% OMMT increases the flexural modulus by 8% and 15% respectively only, that is 1% OMMT does not show a marked increase in the flexural modulus This is most probably due to the low interaction between nanoparticles dispersed in the matrix. Also the Fig. 6 shows that on hybridizing 10% OMMT the flexural modulus decreases by 9% as compared to unhybridized composites. This decrease in elastic properties is related to the very high viscosity of the mix.

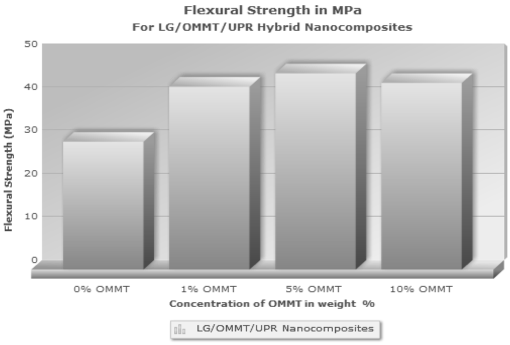

FIGURE 5: Effect of Hybridization on Flexural Strength

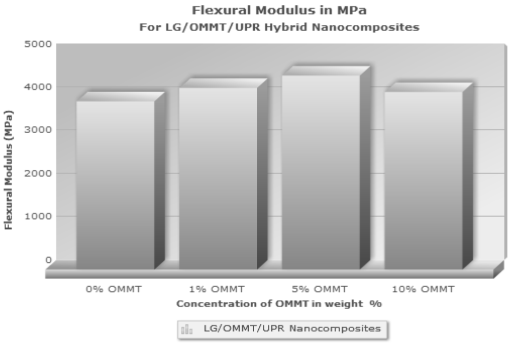

FIGURE 6: Effect of Hybridization on Flexural Modulus

4.3 Effect of OMMT Hybridization on notched & unnotched impact properties:

The impact properties determine the ability of a material to absorb and withstand an impact load, which depends on material toughness. The Fig. 7 and 8 illustrates the notched and unnotched impact strength. The nanocomposites with 1% OMMT shows an increase by 25% whereas the nanocomposites with 5% OMMT shows an increase by 51%. Further increasing the percentage of the OMMT to 10% decreases the notched impact strength by 17%.

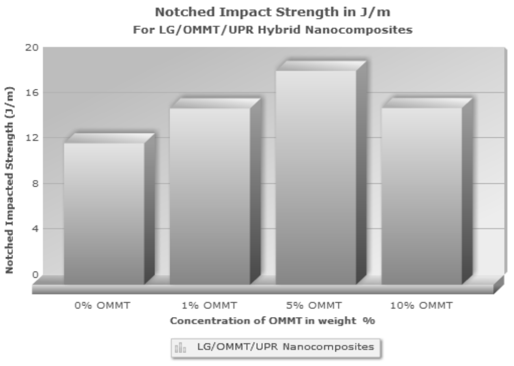

FIGURE 7: Effect of Hybridization on Notched Impact Strength

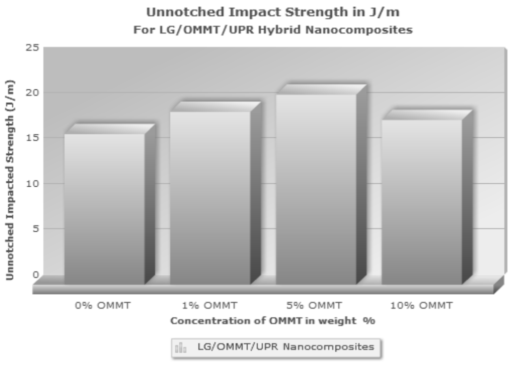

FIGURE 8: Effect of Hybridization on Unnotched Impact Strength

The unnotched impact strength of the hybrid nanocomposites increases by 14% and 26% as the percentage of OMMT is hybridized 1%and 5% respectively. Further as the percentage of the OMMT is increased to 10%, the value of the unnotched impact strength is decreased by 13 % as compared to the 5% OMMT hybrid nanocomposites.

4.4 Effect of OMMT Hybridization on the Chemical Resistance

The weight gain/loss for the neat unsaturated polyester and organically modified clay hybridized LGF/UPR nanocomposites with various chemicals are shown in Fig. 9. In all studied the effect of chemicals show that there is increase in weight with period and clay content, except in case of sodium hydroxide. The swelling of composites indicates the expandable nature of the clay due to absorption of solvent water in their interstices. This is amply indicated by the maximum weight gain of 2.4 % attained in 10 % nitric acid and of 2.45% attained in 10 % aqueous ammonia (Fig. 9b, d). The 10% OMMT hybrid nanocomposite shows a least weight gain of 0.8% in case of 10% hydrochloric (Fig. 9c) and a weight gain of 0.92% in case of 10% sodium carbonate (Fig. 9e). In contrast, alkaline solution 10 % sodium hydroxide has effected considerable weight loss in the matrices (11.8 %) indicating heavy cation exchange within the clay matrices replacing heavier ions of aluminium and iron with lighter sodium ions (Fig. 9f). Intermediate characteristics have been observed in all other solutions. It could be noted that the weight loss or gain suffered by the composites is in direct proportion to the amount of clay introduced in polymer matrices.

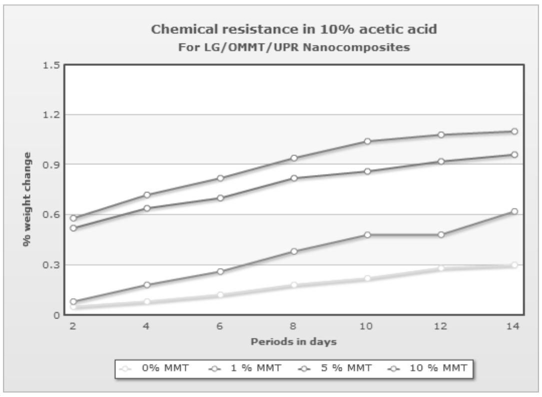

FIGURE 9(a): Effect of 10% Acetic Acid on LGF/OMMT/UPR Hybrid Nanocomposites

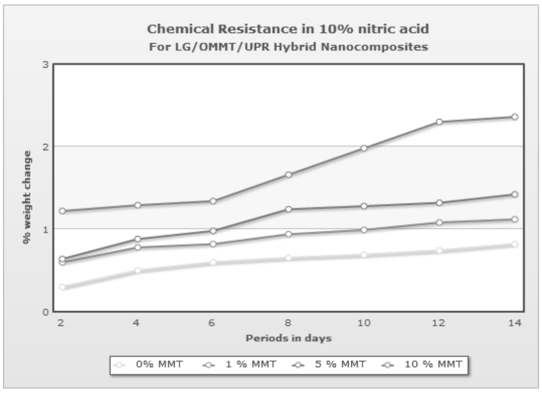

FIGURE 9(b): Effect of 10% Nitric Acid on LGF/OMMT/UPR Hybrid Nanocomposites

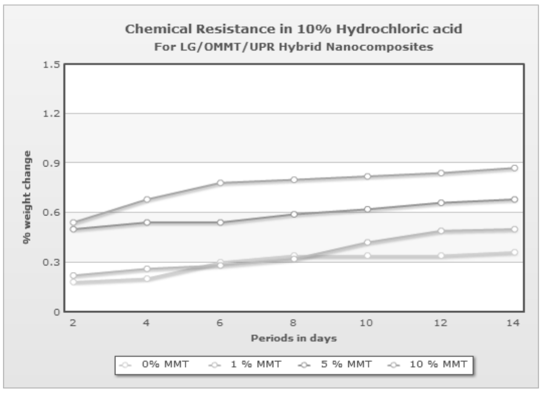

FIGURE 9(c): Effect of 10% Hydrochloric Acid on LGF/OMMT/UPR Hybrid Nanocomposites

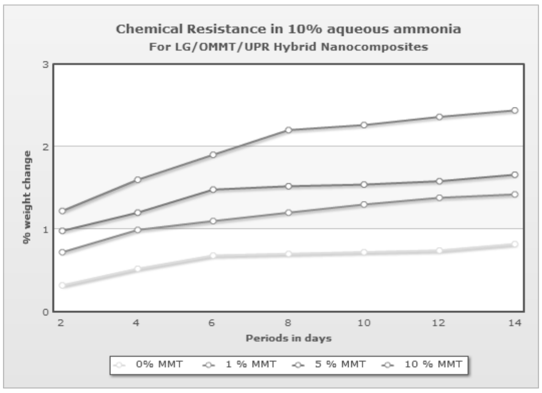

FIGURE 9(d): Effect of 10% Aqueous Ammonia on LGF/OMMT/UPR Hybrid Nanocomposites

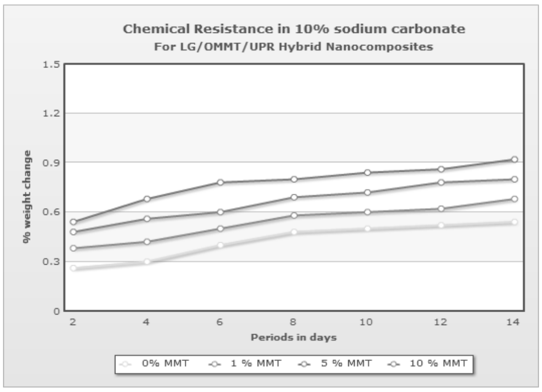

FIGURE 9(e): Effect of 10% Sodium carbonate on LGF/OMMT/UPR Hybrid Nanocomposites

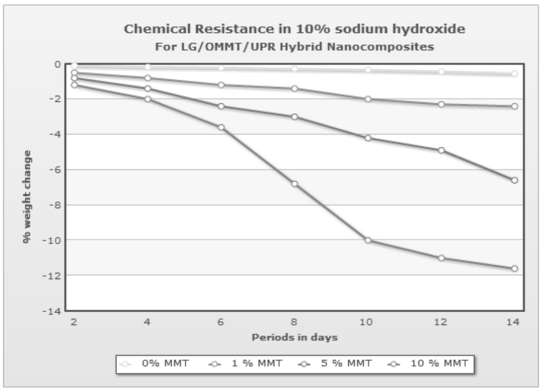

FIGURE 9(f): Effect of 10% Sodium Hydroxide on LGF/OMMT/UPR Hybrid Nanocomposites

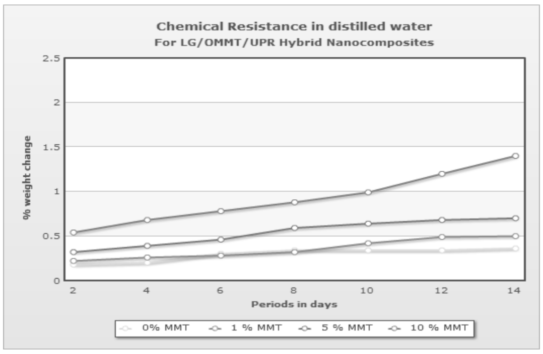

FIGURE 9(g): Effect of Distilled water on LGF/OMMT/UPR Hybrid Nanocomposites

4.5 Effect of OMMT Hybridization on the fiber surface topology

Scanning electron microscopic analysis examined the surface topology of treated unhybrid LGF nanocomposites and hybrid LGF nanocomposites. Fig. 10 (a), (b), (c) and (d) shows the SEM of the unhybridized LG/UPR composites, 1% OMMT hybridized LG/OMMT/UPR nanocomposites, 5% OMMT hybridized LG/OMMT/UPR nanocomposites and 10% OMMT hybridized LG/OMMT/UPR nanocomposites respectively.

The hybridization of the lignocellulosic fibers with OMMT increases the surface roughness in nanoscale level. Rough and groove like portions and protruding structures made the fiber surface very rough and is advantageous for fiber-matrix adhesion as it facilitates both mechanical interlocking and the bonding reaction. There is strong evidence that physical microstructure changes occurred at the fiber surface due to attachment of the nanoscale organo modified MMT clay. These effects on natural fibers are of particular importance increasing the active fiber surface available for adhesion and bonding with the matrix. The natural fibers are hydrophilic in nature whereas OMMT are hydrophobic in nature, therefore hybridizing the fibers with the OMMT makes the natural fiber surface hydrophobic in nature and thus promotes wet ability provides better bonding.

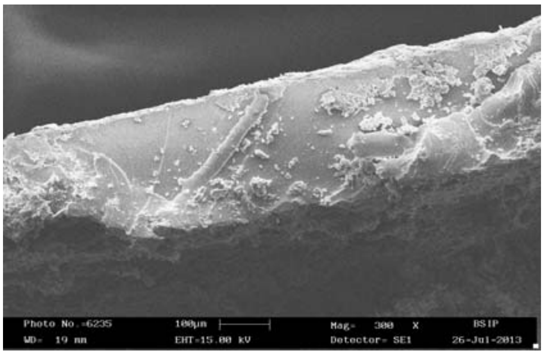

FIGURE 10(a): SEM image of Unhybridized (0% OMMT) LGF/UPR Composites

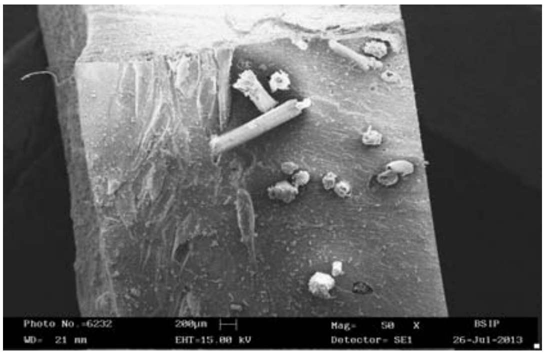

FIGURE 10(b): SEM image of Hybridized (1%) LGF/OMMT/UPR Hybrid NanoComposites

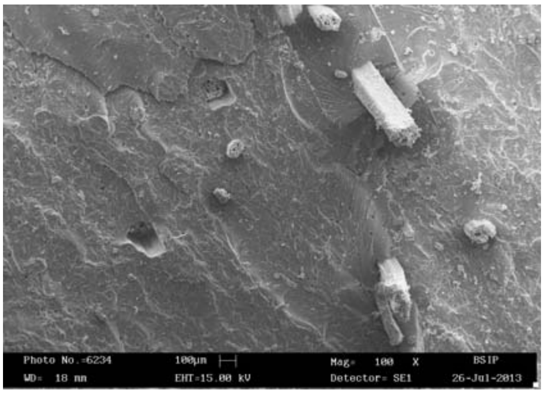

FIGURE 10(c): SEM image of Hybridized (5%) LGF/OMMT/UPR Hybrid NanoComposites

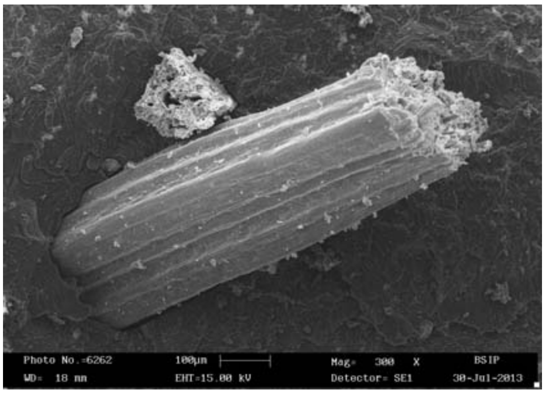

FIGURE 10(b): SEM image of Hybridized (10%) LGF/OMMT/UPR Hybrid NanoComposites

5. CONCLUSIONS

Natural fiber composites are largely driven by increasing environmental awareness. Additionally, the materials' low cost, low density, acceptable specific properties, ease of separation, enhanced energy recovery, CO_2 neutrality, biodegradability, and recyclable properties, have focused attention on natural fiber use in composites. Demand is growing for component materials that are durable, reliable, lightweight, and with excellent mechanical properties that are significantly better than those of traditional materials.

The current research is a successful attempt to make a useful polymer composite sheet from distillery waste and achieved moderate strength and increased chemical resistance. The fiber surface was modified by hybridizing the LG lignocellulosic fibers with hydrophobic OMMT.

Scanning electron microscopic analysis examined the surface topology of unhybridized and hybridized fibers. The active interfacial surface area between natural fiber and polymer matrix has been modified in nanoscale thus provides more bond networking within the same space. The SEM images show more roughness as the percentage of OMMT has been increased from 0% to 10%. Moreover the hydrophobic nature of the OMMT used helps good wettability and facilitates both mechanical interlocking and the bonding strength of the lignocellulosic fiber-polymer interfacial region. This can be explained by increased mechanical properties such as tensile strength, tensile modulus, flexural strength, flexural modulus, notched and unnotched impact strength. The maximum improvement of the mechanical properties is observed with the 5% OMMT hybrid nanoconposites.

The tensile strength and tensile modulus were increased to 41% and 83% respectively, as compared to unhybridized fiber composites, similarly the flexural strength and flexural modulus increased to 53% and 15% respectively as compared to unhybridized fiber composites. The increase in notched and unnotched impact strength is up to 51% and 26% respectively, as compared to unhybridized fiber composites. Best dispersion of nanoparticles in the present research work is limited to 5% for lemongrass hybrid nanocomposites. This may be due to the formation of agglomerates during dispersion of 10% OMMT with the UPR matrix, which have decreased the elastic response of the composite laminates. Agglomerates may have caused material discontinuity and microcracking thus decreasing the mechanical properties at 10% OMMT hybridization.

Among the different concentration of OMMT hybrid nanocomposites, the effects of 10% OMMT nanocomposites is more as compared to the rest of the composites. The chemical resistance graphs show a maximum weight gain of 2.4 % attained in 10 % nitric acid and of 2.45% attained in 10 % aqueous ammonia and a least weight gain of 0.8% in case of 10% hydrochloric. In contrast, alkaline solution 10 % sodium hydroxide has effected considerable weight loss in the matrices of 11.8% indicating heavy cation exchange within the clay matrices replacing heavier ions of aluminium and iron with lighter sodium ions. It could be noted that the weight loss or gain suffered by the composites is in direct proportion to the amount of clay introduced in polymer matrices.

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