Mechanical Properties of Flax Fiber Based Polymer (with Nano Additives) Matrix Composites

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***Abstract* - This study has been conducted in order to examine and investigate the use of a natural material. While synthetic fibers are limited with regard to resources needed for their production, natural fibers are always renewable and degradable, and their required life-time and strength are comparable with those of synthetic fibers. In the present study, the application fields of natural fibers, technical properties of natural fibers, types of natural fibers, fiber treatment methods, chemical structures of natural fibers, natural fiber compatible matrix materials, limitations and renewability of natural fibers are analysed. Flax fiber polymer matrix (with nano additives) composites were fabricated using fibers with treated and untreated surface. Composite coupons were tested by tension till failure. Mechanical behaviour of materials with treated and untreated fibers were compared and analysed.**

***Keywods* – flax fibers, nano additives, matrix composites**

I. Introduction to Natural Fiber Composites

In the recent years, with the growing composite industry, natural fibers have begun to play a great role. However, at the moment, their high cost is restricting their wide usage. Currently, natural fibers are widely used while being friendly to the environment. Most solutions have been developed for non-structural parts for the automotive industry such as covers, car doors panels and car roofs with short natural fibers [1]. There are also some studies regarding structural implementations based on natural fiber reinforcement. Important direction of these studies is concern with housing applications where structural panels and sandwich beams are manufactured out of natural fibers and are used as roofs. Considering the high performance in terms of durability, green availability, recyclable, biodegradability, moderate mechanical properties, low weight, maintenance and cost effectiveness, sustainability, natural fibers reinforcing composites have great potential in the market. It is worth to mention that in addition natural fibers possess good acoustic and thermal insulation properties with their low density and cellular structure [1]. Natural fibers have rapidly emerged as a great alternative for glass fiber. Nowadays, natural fibers are used in construction and automotive industries. At the same time, the use of natural fiber composites is still growing and developing. Typically, they are used with thermoset resin families: polyesters, vinyl esters and epoxies. Thermoplastic resin matrices also are those commonly encountered: polypropylene, low density polyethylene (LDPE), high density polyethylene (HDPE), polystyrene, Nylon 6 and Nylon 6,6 systems. Soy-based resin systems also are getting vogue in some particular applications. Nano additives such as nano clay, nano carbon, nano tubes and others may be used in combination with polymer matrix with the goal to improve matrix toughness and strength. Natural fiber systems can be classified into several categories as shown in Table I. Commonly used fiber types in engineering implementations are presented in bold type.

TABLE I

Categories of Natural Fiber Systems

Bast Fibers	**Flax**, **Hemp**, **Kenaf**, **Jute**, Mesta, **Ramie**, Urena, Roselle.
Leaf Fibers	Pineapple, Banana, **Sisal**, Screw Pine, **Abaca**, Curaua, Agaves, Cabuja, Henequen, Date Palm, African Palm.
Seed Fibers	**Cotton**, Kapok.
Fruit Fibers	Coconut, **Coir**.
Wood Fibers	Hardwoods, Softwoods – many types (~10,000 varieties)
Grasses and Reeds	Wheat, Oat, Barley, Rice, Bamboo, Bagasse, Reed, Corn, Rape, Rye, Esparto, Elephant Grass, Canary Grass.

Growing conditions are one of the most important parameters for natural fibers [2]. Natural fibers can be sorted by their origins: animal, vegetable and mineral. The most extensively used natural fibers are ones of vegetable origin due to their availability and renewability. Therefore, natural fibers are usually referred to as vegetable origin natural fiber in engineering studies. In the past, natural fibers were not regarded as reinforcement material in polymeric matrix due to the following reasons [1]:

- Low thermal stability and possibility of degradation at specific temperatures.
- Hydrophilic nature of natural fibers might cause some problems: poor adhesion between fiber and hydrophobic polymer matrix, swelling and maceration of fibers.
- Properties variability depending on the quality of the harvest, age and body of the plant from which they are extracted, the extraction techniques and the environmental conditions of the site.

Due to all these drawbacks, natural fibers were less attractive than synthetic fibers for many years. However, production of synthetic fibers needs large amount of energy due to processing conditions. This is another significant environmental advantage of natural fibers. Energy need for production of natural fibers is less than a half of that needed for synthetic fibers. Thus, natural fibers gain new interest as

a nonabrasive, non irritating, combustible, nontoxic material with biodegradable properties, low energy consumption for production, budget zero CO_2 emissions if burned, low cost [1]. There is a parameter which describes environmental impact of a product, it is referred to as *embodied energy;* based upon all related agricultural operations (from ploughing to harvest), fiber extraction operations retting and decortication), fiber preparation operations (hackling and carding), fiber processing operations (spinning or finishing) and materials used for these operations . Flax fiber production seems to be the most environmental friendly option, only production of mat fabrics needs relatively less embodied energy comparing with glass fibers [1].

Mechanical properties of natural fibers depend on the type of cellulose and geometry of their elementary cells. The celluloses chains are arranged parallel to each other, forming bundles each containing forty or more cellulosic macromolecules linked by hydrogen bonds and through links with amorphous hemicelluloses and lignin, which confer stiffness to fiber called microfibrils (see Fig.1) [3].

As every other material, natural fiber reinforced polymer matrix composites have pros and cons. Natural fiber-polymer composites might be seen as an optimal solution in selecting construction materials.

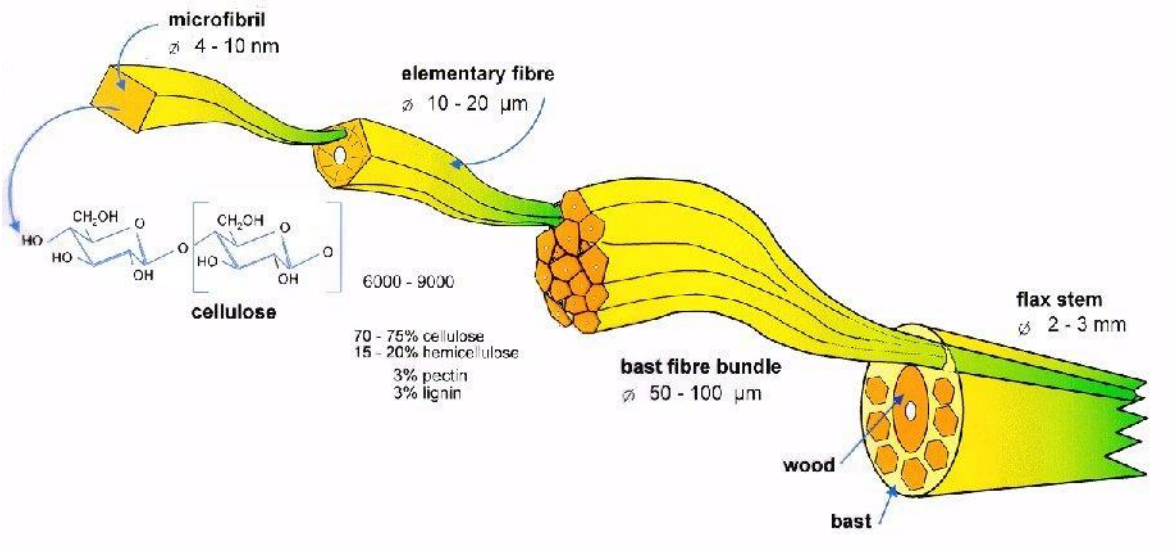


Fig. 1. Flax fiber structure [3]

II. Structure And Composition Of Natural Fibers

The cell walls of natural fibers are not in a homogenous membrane. Each fibril (see Figure 1) has a complex layered structure, which consists of a primary wall which is the first layer deposited during the cell growth for the secondary wall formation [4]. The secondary wall consists of three different layers and the middle layer is the thickest one, it determines the mechanical performance of the fiber. The middle layer is made up of an aligned helically wound cellular microfibrils which consist of long cellulosic molecule chain. The angle between the microfibrils and the axis of the fiber is called *the microfibrillar angle*. This parameter shows variety in every fiber. The outer secondary cell wall (SI) consists of four to six lamella, which spiral around the tracheis longitudinal axis in opposite directions, and has comparable thickness to the primary wall. The principal bulk of the secondary wall might be as thin as 1 pm in thickness in early woods and shows variety up to 5 pm in summer woods. It is contained in the middle secondary cell wall (S2). The microfibrils of the secondary wall spiral highly in the axial direction at an angle of approximately 10 - 20°. The inner secondary wall (S3) is also called *the tertiary wall.* The inner secondary wall could be unformed and neglected in mathematical calculations. However, the thickness and the orientation of the microfibrils in the middle secondary wall are important in terms of mechanical properties [4].

Mechanical properties of a natural fiber reinforced composite highly depend on the microfibril angle and the cellulose content. To obtain a desired fiber for composite material applications, cellulose content must be high and microfibril angle must be low [4].

The fiber chemical treatment is based on selective removal of non-cellulosic compounds. In fiber bundle integration, individual fiber strength and fiber bundle strength as well as elasticity, wet strength, swelling and water absorbency of both the pectic and hemicellulosic materials play an important role [4].

III. Natural Fiber Fabric Types and Use of Fibers

The choice to use short or continuous fibers in a composite material depends on the desired technical properties and specific optimisation parameters. While natural fibers not always possess continuous fibers due to their length conditioned by their natural origin, it is common and easy to produce continuous fiber of desired dimensions in case of synthetic fiber. This is one of the major reasons why natural fibers are mainly used as short fiber reinforcements in composite productions. If high stress and preferred direction of load are not required, discontinuous (chopped) fibers might be used, as discontinuous fibers are generally used in random orientation [1].

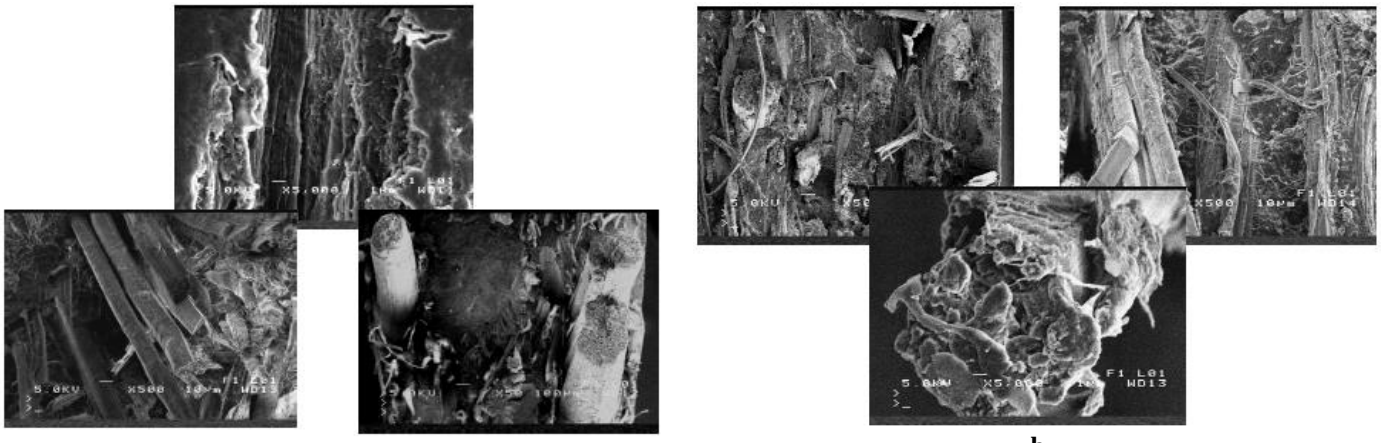
Long Yarns: A yarn is a continuous short fiber assembly which is interlocked. These are suitable for knitting, embroidery, ropemaking, textiles, crocheting and sandwich composite production. To provide axial strength of the yarn, the fibers are twisted with an angle to axis of the yarn. To make a cohesive thread, spun yarns are made with bonding staple fibers together or made by twisting. It is also possible to obtain a thicker twisted yarn by twisting two or more spun yarns together. The yarns might be called z-twist or s-twist depending on the direction of the final twist. More than one parallel spun yarns could form a *roving*. The principal advantage of natural fiber yarns is the possibility to weave them in the desired directions in both 2D and 3D [1].

The unit which is used to measure yarns is called the *denier* which helps to determine the linear mass density of the yarns, which is expressed as grams per 9000 meters.

Spun yarns are generally obtained from the protruding parts of natural fibers as short fibers. These fibers are usually called yarn hairiness. In many cases, yarn hairiness is not desired. However, it demonstrates better mechanical properties in interlocked yarns due to better transverse properties [1].

Low level of twist of natural yarns shows low strength. Especially higher twist level is required to improve the strength for short length of fibers.

The amount of twist also effects the impregnation of reinforced composites; it has an influence on the quality and mechanical properties of the composites. Penetrating resin into a yarn becomes more difficult with the increasing twist level due to increasing compact structure. In addition, dry yarns show lower bonding between resin and yarns. Therefore, they have lower tensile properties due to delamination. For all these reasons, an optimal twist level must be achieved [5]. The fiber direction to stress direction must be taken into account considering the mechanical properties of the composite. Although mat fiber type of natural fibers costs less than other types , they have lower tensile properties [1].



a **b**

Fig. 2. SEM photography demonstrates a) poor interface b) good interface by chemical treatment between fiber and matrix [6].

The contribution of fibers to the final properties of the composite depends on: mechanical properties of fibers; type (continuous/ discontinuous) and orientation of fibers in the composite (anisotropy); volume fraction of fibers; fiber-matrix interface; processing technique used for composite manufacturing. Disadvantages of natural fiber must be dealt with before using them in polymer composites. The most serious concern with natural fibers is their hydrophilic nature due to the presence of pendant hydroxyl and polar groups in various constituents, which can lead to poor adhesion between fibers and hydrophobic matrix polymers [1]. The hydrophilic nature of the fiber surface also leads to high moisture uptake of the natural fibers which can seriously lower the mechanical properties of the fibers themselves [1]. Natural fibers are inherently incompatible with nonpolar-hydrophobic thermoplastics, such as polyolefins. Moreover, difficulty in mixing because of poor wetting of the fibers with the matrix is another problem that leads to composites with weak interface [1]. There are some types of physical fiber treatment, and the most common are chemical ones. These treatments can clean the fiber surface, modify the chemistry on the surface, lower the moisture uptake and increase the surface roughness [6]. As natural fibers bear hydroxyl groups from cellulose and lignin, they are subject to chemical modification. The hydroxyl groups may be involved in the hydrogen bonding within the cellulose molecules thereby reducing the activity towards the matrix. Chemical modifications may activate these groups or can introduce new moieties that can effectively lead to chemical interlock with the matrix. Mercerization, isocyanate treatment, acrylation, permanganate treatment, acetylation, silane treatment and peroxide treatment with various coupling agents and other pretreatments of natural fibers have achieved various levels of success for improving fiber strength, fiber fitness and fiber-matrix adhesion (Figure 2). Some of these treatments are described further: **Alkali treatment** of natural fibers, also called mercerization, is the common method to

produce high-quality fibers. The formula of the reaction is: Fiber-OH + NaOH → Fiber-O-Na^+ + H_2O Mercerization leads to fibrillation which causes the breaking down of the composite fiber bundle into smaller fibers. Mercerization reduces fiber diameter, thereby increases the aspect ratio which leads to the development of a rough surface topography that results in better fiber-matrix interface adhesion and an increase in mechanical properties; **acetylation** improves dimensional stability and environmental degradation and contributes to the introduction of plasticates in cellulosic fibers by esterification. Acetylation is based on the reaction of cell wall hydroxyl groups of lignocellulosic materials with acetic or propionic anhydride at elevated temperature. Pretreatment of fibers with acetic anhydride substitutes the polymer hydroxyl groups of the cell wall with acetyl groups, modifying the properties of these polymers [1]; **peroxide** treatment of cellulose is comparatively easily performable and this treatment makes improvements in mechanical properties. Organic peroxides tend to decompose easily to free radicals, which further react with the hydrogen group of the matrix and cellulose fibers. In peroxide treatment, fibers are treated with 6% benzoyl peroxide or dicumyl peroxide in acetone solution for about 30 min after alkali conducted at a temperature of 70°C to support the decomposition of the peroxide [7]; **graft copolymerization** by creation of an active site, a free radical or a chemical group which may get involved in an ionic polymerization or in a condensation process, on the preexisting polymeric backbone is one of the common methods. Polymerization of an appropriate monomer (e.g. benzoyl chloride, maleated polypropylene/ maleic anhydride MAH-PP, acrylation, titanate) onto this activated back-bone polymer leads to the formation of a graft copolymer with a higher surface energy and wettability and adhesion interface by polymer matrix.

Maleic anhydride treatment greatly reduces water absorption in hemp, banana and sisal fibers and their composites [1]; **coupling agents treatment** usually improves the degree of cross-linking in the interface region and offers a perfect bonding. Among the various coupling agents, silane coupling agents were found to be effective in modifying the natural fiber-matrix interface. [1]; **permanganate treatment**. Pretreatments with permanganate are conducted by using different concentration of potassium permanganate ($KMnO_4$) solution in acetone with soaking duration from 1 to 3 min after alkaline pretreatment. As a result of permanganate treatment, the hydrophilic tendency of the fibers is reduced, and thus, the water absorption of fiber-reinforced composite decreases with increase in $KMnO_4$. Permanganate treatment is indicated as one of the best methods to improve the bonding at the fiber-polymer interface [1]; **plasma treatment** is an effective method to modify the surface of natural polymers without changing their bulk properties. The plasma discharge can be generated by either corona treatment or cold plasma treatment. Both methods are considered as a plasma treatment when ionized gas has an equivalent number of positive and negative charged molecules that react with the surface of the present material [8].

IV. Mechanical Behaviors of Natural Fiber Composites

Basically, having high tensile properties means also having improved mechanical properties of a composite material. Markedly, most common use of fiber reinforcement is with polymer matrix. Considering tensile strength and young modulus of flax fiber, PP and polyester resin, tensile strength of flax fiber is 12-57 times greater than PP resin and 6-16 times greater than polyester resin, young modulus of flax fiber is 16-29 times greater than PP resin and 6-14 times greater than polyester resin [10]. As generally accepted, high rates of fiber are desired to obtain high performance in mechanical properties in short fiber reinforced polymeric composites. Therefore, effect of rates of natural fiber in polymeric matrix composites is a significant subject for a great number of researches.

V. Analytical Modeling

1. A semi-empirical modification of the rule of mixtures for strength prediction of polymer natural fibers composites were used by authors [12] in a form:

$$\sigma_W = \sigma_{FU}(1\text{-}l_c/2l)V_F + \sigma^\circ_M(1 - V_F),\ l \geq l_c \quad (1)$$

The modified equation for cylindrical fibers:

$$\sigma_W = a\tau_i V_F(l/d) + \sigma^\circ_M(1 - V_F),\ l \leq l_c \quad (2)$$

The modified equation for rectangular fibers:

$$\sigma_W = a\tau_i V_F(l/2)[(W+T)/WT] + \sigma^\circ_M(1 - V_F),\ l \leq l_c \quad (3)$$

σ_W, a, τ_i, σ°_M, l ,l_c, V_F, d, W, T parameters symbolize composite tensile strength, the clustering parameter, interfacial shear strength, maximum stress evaluated at the peak composite strength, fiber length, critical fiber length, fiber volume fraction, cylindrical fiber diameter, rectangular fiber width, rectangular fiber thickness, respectively. These parameters allow predicting the tensile strength of natural fibers composites (with HDPE matrix as well) [12]. Hereby, the short fiber is assumed as perfectly aligned and there is no fiber curvature. In this respect, experimental approaches are important for determining the interfacial shear strength (τ_i,) of the fiber with fiber pullout or fragmentation tests.

The rule of mixture for Young modulus calculation is expressed by the following equation (ROM):

$$E = E_F V_F + E_M V_M \quad (4)$$

E_F, V_F, E_M and V_M are the modulus and volume fractions of the fiber and matrix and E is the modulus of a composite.

2. Inverse/transverse rule of mixtures (IROM) [9]:

$$E = E_F V_F / (V_M E_F + V_F E_M) \quad (5)$$

E_F, V_F, E_M and V_M are the modulus and volume fractions of the fiber and matrix and E is the modulus of a composite [5].

3. Halpin-Tsai Equation [9]:

$$E = E_M[(1 + \xi\eta V_F) / (1 - \eta V_F)] \quad (6)$$

η is given as:

$$\eta = [(E_F/E_M) - 1] / [(E_F/E_M) + \xi] \quad (7)$$

ξ in equation (6) and (7) is a shape fitting parameter to fit Halpin-Tsai equation to experimental data. η - the average number of fibre–fibre contact points. E_F, E_M are the modules of fiber and matrix;

The parameter ξ has an importance for the packing arrangement and the geometry of the reinforcing fibers [9].

There are variants of equations depending on the shape of the particle and on the modulus that is predicted for ξ in the literature. If the tensile modulus in the fiber direction is desired, and the fibers are rectangular or circular in shape, the equations are:

4. Shear-lag theory [9]:

$$E = E_F[1 - (\tanh(\eta L / 2)) / (\eta L / 2)]V_F + E_M V_M \quad (9)$$

$$\eta = (1/r)[2E_M/E_F(1 + V_M)\ln(P_F/V_F)]^{1/2} \quad (10)$$

$$E = E_1 3/8 + E_2 5/8 \quad (11)$$

E is the elastic modulus of the composite. E_1 and E_2 are the elastic moduli of randomly oriented fiber reinforced composites.

$$E_i = E_M[(1 + \xi_i\eta_i V_F) / (1 - \eta_i V_F)], \quad (12)$$

$$\eta_i = [(E_F/E_M) - 1] / [(E_F/E_M) + \xi_i]$$

$\xi_i = 2(l_f / d_f)$ for i = 1 or $\xi_i = 0.5$ for i = 2.

A model was proposed by Mendel et al. to calculate stress fields with the exception that a decay function was used to model previously neglected changes of axial stress in the radial direction. Shear-lag parameter is presented by Mendel et. al. [12]:

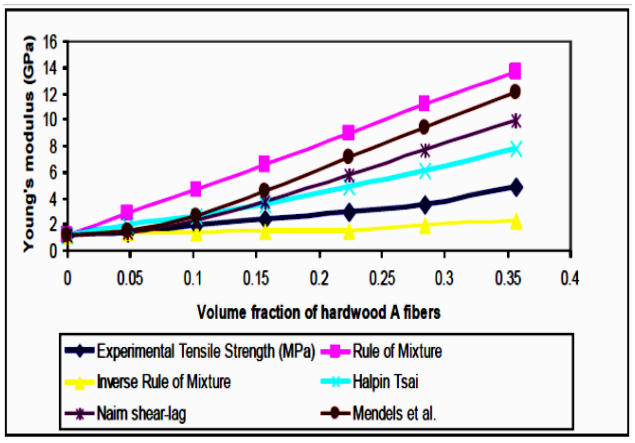
$$\eta = [K_c(r^2E_F(r_1^2 - r^2)E_M / rE_F(1 + V_M)]^{1/2} \quad (13)$$

r_1 represents the radius where the shear stress is zero and the matrix is not influenced by stress transfer between the fibre and matrix [12]. If r_1 is influenced by stress, r_1 is determined as:

$$r_1 = rE_F/E_M \quad (14)$$

K_c is defined as:

$$K_c = 12[2(r_1 - r) + \psi_c(r_1^2 - r^2)]/r\{24r(r_1^2 - r^2) - \\ -16(r_1^3 - r^3) - 3\psi_c(r^2 - r_1^2)^2 + \\ +6r_1(2 + \psi_c r_1)[2r_1^2\ln(r_1/r) - (r_1^2 - r^2)]\} \quad (15)$$



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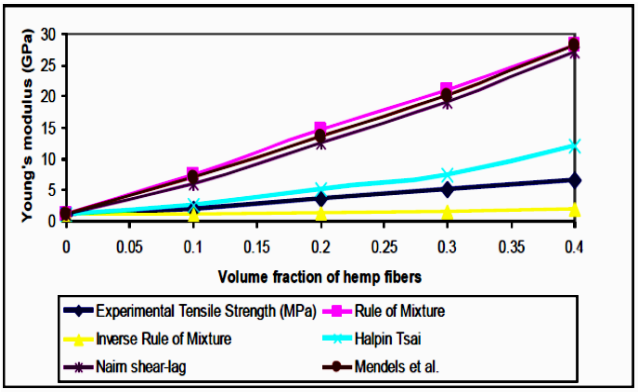

b

Fig.3. (a) Different volume fraction according to experimental young modulus of hardwood A fiber reinforced HDPE composites;

Figures 3a, b present the experimental and the calculated results with different methods of determination the young modulus of hemp hard and hardwood reinforced HDPE composites with increasing content of fibers [9]. The figures show that the most precise method of calculation is Halpin-Tsai model to predict the experimental results.

VI. Preparation and Analysis

Four s-twisted flax yarns of different thicknesses of 2.7, 1.9, 1.35 and 0.7 mm were used and numbered (Table 2.). Additionally, the flax yarn, which has 2.7 mm thickness was opened with an opposite motion to twist direction in order to obtain roving flax fibers. In order to prepare three samples from each of yarns and fiber, planning to prepare also treated flax fiber composites, six sample groups from each yarn and fiber of total thirty sample groups were cut into 160 mm length of the same weights (4) g with % 2 tolerance) (Figure 4). Afterwards, distillated water was poured in a sterile bowl and 1-2 drop of detergent was added. Subsequently, the first fifteen yarn and fiber sample groups were washed by three groups, then, the bowl was cleaned and the yarn and roving washing was repeated with the second half of the distillated water and the remaining fifteen sample groups. After the roving and yarn washing, the yarns and fibers were put in a semi-open oven on clean metal plates as five groups at 70 °C during 20 hours for drying (Figure 5). Then the drying process was completed at room temperature for 72 hours.

TABLE II

S-TWISTED FLAX YARNS OF DIFFERENT THICKNESSES

No.1	No.2	No.3	No.4	No.5
2.7 mm	1.9 mm	1.35 mm	0.7 mm	Open-roving

Three sample groups from each yarn and fiber were separated for surface treatment. 5 % NaOH by weight solution was prepared and the yarns and the fiber were soaked in the solution for 2 hours. Afterwards, the yarns and the fiber were washed in the distillated water - 1.5 % HCl solution in order to clean the yarns and the fiber and neutralize the fiber surface. After cleaning, the yarns and the fiber were put in an oven at 70 °C during 15 hours and then during 16 hours were left in the air to dry the fibers. Thirty composite sample molds were prepared from plywood having dimensions 163 x 30 x 8 mm. The corners and the bottom were sealed with tape for impermeability and smooth bottom surface. The lateral surface of the molds was lubricated with oil to facilitate ejection of the samples from the molds. The fiber and yarns were aligned in molds (Figure 6a). Subsequently, the epoxy resin was mixed with 2% hardener and filled into the molds. After 24 hours, shrinkage was observed due to liquid absorption of the yarns and fibers in interfaces. Afterwards, the epoxy resin was embedded in order to fill the molds completely. After 24 hours, the composite samples were ejected with circular saw (Figure 6b). Thereby, 7.2 % by weight, flax fiber reinforced epoxy resin composites were obtained.

Figure 4. The six groups from each yarn and fiber type

Fig. 5. The oven at 70 °C and fiber yarns on the plate

VII. RESULTS AND DISCUSSION

a

b

Fig. 6.(a) Aligned fiber and yarns in the molds; (b) Flax fiber reinforced epoxy resin composite samples, treated and untreated types

The tensile strength of untreated No.1 reinforced composite sample is around 40 MPa and while the tensile strengths of untreated No.2, No.3 and No.4 reinforced composite samples are around 35 MPa, No.5 reinforced composite sample has tied yarns. Figure 7 demonstrates the alkali treated flax fiber yarn and the untreated fiber yarn. While the untreated yarn has a laciniate form, the alkali treated yarn has a more compact form and relatively smoother yarn surface.

Fig. 7. (a) untreated flax fiber yarn, (b) treated flax fiber yarn.

The tensile stress tests have been made with Zwick/Roell Z150 universal testing machine (Figures 8-9). Similarly, alkali treated No.1 reinforced composite differed from treated No.2, No.3 and No.4 with its relatively higher tensile strength of 46 MPa. The tensile strength of alkali treated No.2, No.3 and No.4 composite samples is around 40 MPa. Likewise, No.5 reinforced composite has shown a lower tensile strength with 34 MPa value.

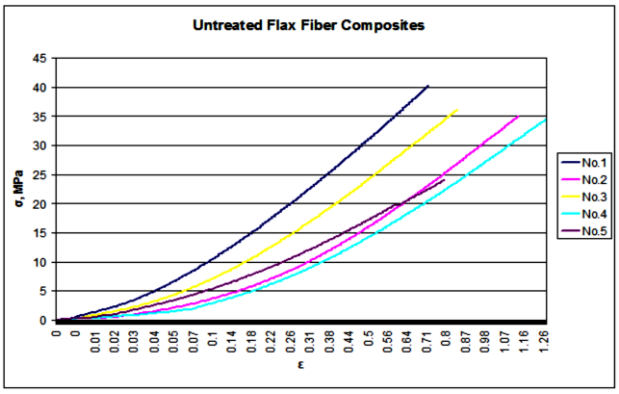

Fig.8. Stress –deformation curves for untreated No.1, No.2, No.3, No.4 and No.5 types of fiber reinforced composites

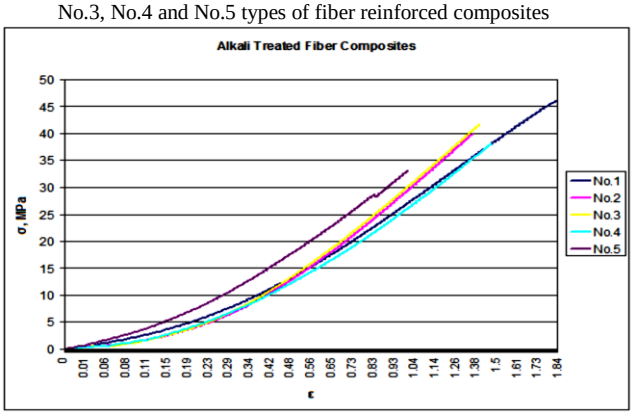

Fig.9. Stress –deformation curves for alkali treated No.1, No.2, No.3, No.4 and No.5 types of fiber reinforced composites

After the tensile stress test, microscopic investigation has been made. A pull out from the center of the yarn has been observed (Figures 10 a,b, 11a). It demonstrates low wettability properties of the matrix material in the center of the thickest yarn. Alkali treated No.1 reinforced composite does not show a high number of pulled out fibers. The polymeric matrix residual might be observed on the yarn cross section. A better adhesion property has been observed (Figure 11b).

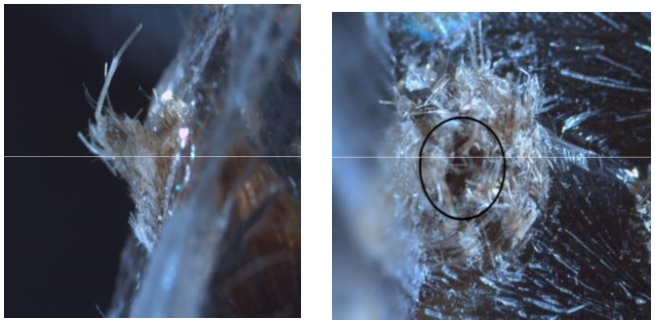

Fig.10 (a, b). Pull out, which has occurred in lateral surfaces

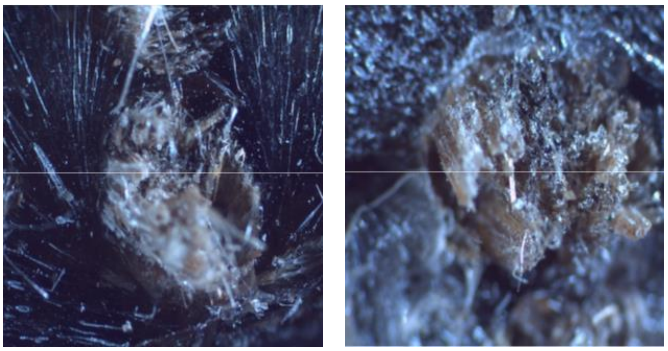

Fig.11. (a) Untreated No.1 reinforced composite after the failure – pull out;(b) Alkali treated No.1 reinforced composite after the failure

VIII. Conclusion

The mechanical performance of natural fiber reinforced composites highly depends on the fiber type, fiber diameters, reinforcing type (unidirectional, mat, short, lamina, hybrid, fabric, etc.), the chosen treatment method, matrix material, twist angle and thickness, production method and fiber content. There are different solutions for specific combinations of fiber characteristics. To obtain an optimal solution, initially fiber type and diameter, surface treatment method and matrix material must be considered in order to provide a higher mechanical performance in terms of improved fiber strength and better adhesion between fiber-matrix.

Studies have demonstrated that each surface treatment has an optimum combination with a particular natural fiber and matrix material. Therefore, the surface treatment methods must be strongly taken into account. Both in the untreated and in the treated fiber composites, No.1 reinforced composites has shown a higher tensile strength due to its more compact structure because of its thicker form. In No.2, No.3 and No.4 reinforced composites, their decreasing thicknesses has provided a higher adhesion surface and better distribution possibilities. On the other hand, their compactness has decreased with decreasing thickness. Hereby, these two competing phenomena provided similar tensile strengths of the composites. In No. 5 reinforced composites, the tensile strengths have been lower due to absence of dimension stability of the flax fiber. Therefore, the fibers action was analogical to short fiber action in the composite. In all treated fiber composite samples higher tensile strengths was observed than in untreated fiber composite samples. The principal effect of alkali treatment is better adhesion properties. Therefore, in the microscopic pictures, better adhesion and wettability have been observed. Also, the twist angle and the thickness of yarn must be considered in terms of wettability, own tensile properties of the yarns. A high twist angle might provide a higher tensile performance due to its more compact structure. On the other hand, wettability of each fiber for washing, chemical treatment and liquid polymer phase would be restricted due to this compact structure.

In general, with increasing fiber content, likewise, the tensile properties of the composites increase. However, there are some circumstances which are able to lead to the reduction of

certain properties. After an increase in tensile strength, it might decrease after reaching a particular content of fiber. The principal reason in such cases is buckling.

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Sahin Altundal, Andrejs Krasnikovs, Inese Telnova, Oskars Linins. Mehāniskās īpašības kompozītiem ar polimēru matricu (ar nanopiedevām) un lina šķiedrām.

Šis pētījums tika veikts, lai pārbaudītu un izmeklētu dabas izcelsmes šķiedru pielietojumu, kuru izmantošanas apjomi pieaug, līdztekus izmantotajiem sintētiskas izcelsmes šķiedrām, kurus ierobežo resursu apjoma samazināšanās. Kamēr sintētiskās šķiedras, tādas kā – metāliskās, silīcija, alumīnija, oglekļa, SiC un stikla šķiedras, ir ierobežotas zemes ierobežoto resursu dēļ, dabīgās šķiedras vienmēr ir atjaunojamas, tās spēj sadalīties pēc to dabīgā dzīves cikla beigām, un to izturība ir pielīdzināma citām sintētiskajām šķiedrām. Pie tam, tā kā tās neprasa sarežģītu apstrādi un augstu enerģijas patēriņu, lai gan tās ierobežo to dabiskā izcelsme, šie materiāli un kompozītmateriāli, kuros tie izmantoti, ir nopietni jāizskata. Šajā pētījumā vispārīgi ir izskatītas dabīgo šķiedru pielietošanas jomas, izmantošanas metodes, dabīgo šķiedru tehniskās īpašības, dabīgo šķiedru veidi, analītiskās pieejas, salīdzinājumi, apstrādes metodes, dabīgo šķiedru ķīmiskā struktūra, dabīgo šķiedru saderības matricas materiāli, dabīgo šķiedru ierobežojumi, un to spēja atjaunoties. Darbā tika veikta dažāda veida lina šķiedru ķīmiskā apstrāde pēc kuras tika izgatavoti lina šķiedru epoksīda matricas kompozīti. Kompozītu paraugi tika mehāniski testēti un to stiprība atkarīgi no šķiedru ķīmiskās apstrādes tika noteikta un salīdzināta

Сахин Алтундал, Андрей Красников, Инесе Тельнова, Оскарс Линьньш. Механические свойства композитов на основе полимерной матрицы (с нанодобавками) и льняных волокон.

Исследование проводилось с целью оценки возможностей использования натуральных волокон в композиционных материалах, содержащих полимерную матрицу. Натуральные волокна, объем производства которых непрерывно возрастает, наряду с синтетическими волокнами, все шире используются в композитной области. Волокна могут быть подразделены согласно их происхождению как на животного происхождения, так и растительного и минерального. Среди волокон натурального происхождения наибольшее значение имеют волокна растительного присхождения. Современные натуральные волокна используются в структурных приложениях, как армирование композиционных материалов. В работе был проведен детальный анализ классов натуральные волокон и используемых полимерных матриц. Представлены формулы, используемые при оценке механических свойств полимерных композитов имеющих полимерную матрицу.Были отобраны льняные волокна поверность которых была обработана химически. Используя обработанные и необработанные волокна были изготовлены композитные образцы призматической формы. Все образцы были испытаны на растяжение. Результаты полученные в экспериментах с химически обработанными и необработанными волокнами сравнивались.