MECHANICAL & THERMAL PROPERTIES OF NATURAL FIBER COMPOSITE MATERIAL

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Abstract

Natural fibers have attracting the interest to engineers, researchers, professionals and scientists all over the world as an alternative reinforcement for fiber reinforced polymer composites, because of its superior properties such as high specific strength, low weight, low cost, fairly good mechanical properties, non-abrasive, eco-friendly and bio-degradable characteristics. Polymer composite materials with vegetable fibers were an attractive field for many industries and researchers, however, these materials required the issues of compatibility between the fibers and the polymeric matrix. This work evaluates the thermal and mechanical properties of Doum-fibers reinforcing a low density polyethylene (LDPE) composite to follow the effect of adding fibers into polymer matrix. Doum-fibers were Alkali treated to clean the fiber surface and improve the polymer/fibers adhesion. The Doum-fibers were compounded in LDPE matrix at various contents and extruded as continuous strands.

Development of the composites with natural fibers and fillers as a sustainable alternative material for some engineering applications, particularly in aerospace applications and automobile applications. Natural fibers such as jute, coir, sisal, bamboo etc. Natural fibers are renewable, cheap, biodegradable, and environment friendly materials. In this paper Hybrid composites are in the form of sisal/Sic/Glass Fiber, jute/sansevieria fiber, sisal/jute fiber, jute/bamboo fiber. The mechanical and Thermal properties are discussed here, for the hybrid composites the Epoxy resin is used as binder, by adding the Filler to the Natural fibers materials we can further improve the performance of the composites.

INTRODUCTION

Over the last decades, natural fibres received increasing attention as alternative to synthetic fibres both from academic world and various industries. There is a variety of different natural fibres, which can be used as reinforcements of polymer composites. Four main reasons make the natural fibres more attractive than others: i.e. specific properties, price, biodegradability and recyclability. Driven by the introduction of regulatory norms demanding more environmental friendly products, the use of natural fibres as reinforcements for composites. Natural fibres such as flax, jute, hemp and knead offer low carbon footprint and biodegradability advantages combined with a high specific strength and stiffness at a low cost. The application of natural fibres is motivated by a combination of environmental sustainability, cost-effectiveness, recycling and biodegradation properties. Natural fibres are used as reinforcement in structural applications in automotive industry. Natural fibres such as hemp and flax are used to manufacture door panels and the roofs of cars.

Natural fibres

Natural fibers are categorized into animal fibers and plant cellulose fibers. Plants that produce natural fibers can be divided into primary and secondary depending on the utilization. Primary plants are grown for their fibers while secondary plants are plants where the fibers are extracted from the waste product. There are six major types of fibers namely; bast fibers, leaf fibers, fruit fibers, grass fibers, straw fibers etc. Generally, much higher mechanical strength and stiffness can be obtained by using plant fibers, but before that, it has to be conditioned mechanically and should undergo certain chemical treatments.

Natural fibres will take a major role in the emerging “green” economy based on energy efficiency, the use of renewable materials in polymer products, industrial processes that reduce carbon emissions and recyclable materials that minimize waste. Natural fibres are a kind of renewable resources, which have been renewed by nature and human ingenuity for thousands of years. They are also carbon neutral; they absorb the equal amount of carbon dioxide they produce. These fibers are completely renewable, environmental friendly, high specific strength, nonabrasive, low cost, and bio-degradability. Due to these characteristics, natural fibers have recently become attractive to researchers and scientists as an alternative method for fibers reinforced composites. This review paper summarized the history of natural fibers and its applications.

Man Made Fiber

Man-made fibers, such as nylon, polyester, and rayon, are produced by chemical reactions controlled by people, rather than occurring naturally. The term synthetic fibers is often used to designate man made fibers; however, to many people, this term has a negative connotation, meaning inauthentic, artificial, or fake. TFPIA classifies man made or manufactured fibers by generic names. Currently, TFPIAN recognizes 26 generic groups of manmade fibers.

Classification of Natural Fibers

Fibers are a class of hair-like material that are continuous filaments or are in discrete elongated pieces, similar to pieces of thread. They can be spun into filaments, thread, or rope. They can be used as a component of composites materials. They can also be matted into sheets to make products such as paper or felt. Fibers are of two types: natural fiber and man made or synthetic fiber. Figure 1 shows the classification of natural fibers.

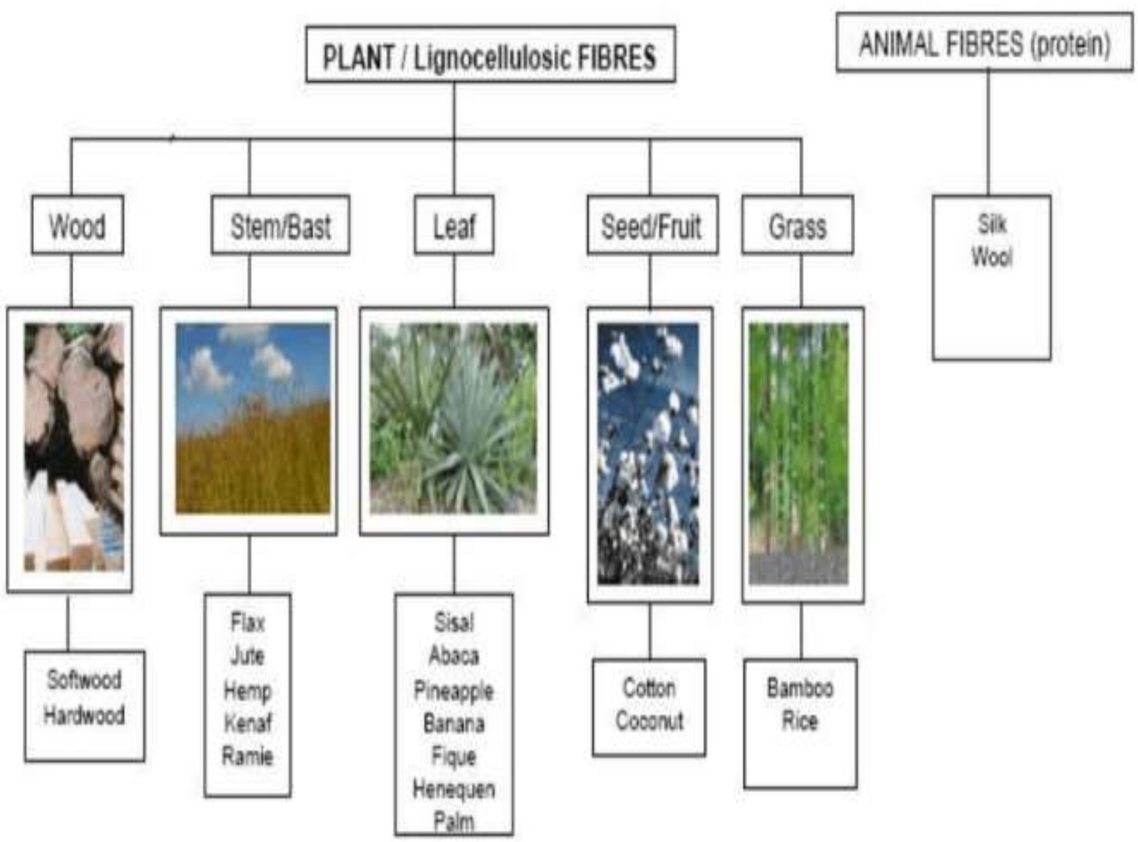

Fig 1: Classification of natural fibers

SOURCES OF NATURAL FIBRES

1. PLANT FIBRES

1. **Abaca:** It's a leaf fibre, composed of long slim cells that form part of the leaf's supporting structure. Lignin content is a high 15%. Abaca is prized for its great mechanical strength, buoyancy, resistance to saltwater damage, and long fibre length – up to 3 m. The best grades of abaca are fine, lustrous, light beige in colour and very strong. Once a favoured source of rope for ship's rigging, abaca shows promise as an energy-saving replacement for glass fibres in automobiles.
2. **Coir:** Among vegetable fibres, coir has one of the highest concentrations of lignin, making it stronger but less flexible than cotton and unsuitable for dyeing. The tensile strength of coir is low compared to abaca, but it has good resistance to microbial action and salt water damage. A coarse, short fibre extracted from the outer shell of coconuts, coir is found in ropes, mattresses, brushes, geotextiles and automobile seats.
3. **Cotton:** It's almost pure cellulose, with softness and breathability that have made it the world's most popular natural fibre. Fibre length varies from 10 to 65 mm, and diameter from 11 to 22 microns. It absorbs moisture readily, which makes cotton clothes comfortable in hot weather, while high tensile strength in soap solutions means they are easy to wash. Cotton is the world's most widely used natural fibre and still the undisputed "king" of the global textiles industry.
4. **Flax:** Like cotton, flax fibre is a cellulose polymer, but its structure is more crystalline, making it stronger, crisper and stiffer to handle, and more easily wrinkled. Flax fibres range in length up to 90 cm, and average 12 to 16 microns in diameter. They absorb and release water quickly, making linen comfortable to wear in hot weather. One of nature's strongest vegetable fibres, flax was also one of the first to be extracted, spun and woven into textiles.
5. **Hemp:** Long, strong and durable, hemp fibres are about 70% cellulose and contain low levels of lignin (around 8-10%). The fibre diameter ranges from 16 to 50 microns. Hemp fibre conducts heat, dyes well, resists mildew, blocks ultraviolet light and has natural anti-bacterial properties. Shorter, woody core fibres ("tow") contain higher levels of lignin. Easy to grow without agrochemicals, hemp is used increasingly in agro textiles, car panels and fibreboard, and "cottoned" for clothing.
6. **Jute:** Dubbed the "golden fibre", jute is long, soft and shiny, with a length of 1 to 4 m and a diameter of from 17 to 20 microns. It is one of nature's strongest vegetable fibres and ranks second only to cotton in terms of production quantity. Jute has high insulating and anti-static properties, moderate moisture regain and low thermal conductivity. The strong threads made from jute fibre are used worldwide in sackcloth - and help sustain the livelihoods of millions of small farmers.
7. **Ramie:** It's is white with a silky lustre, similar to flax in absorbency and density but coarser (25-30 microns). One of the strongest natural fibres, it has low elasticity and dyes easily. Strands of ramie range up to 190 cm in length, with individual cells as long as 40 cm. Trans-fibre fissures make ramie brittle but favour ventilation. Not widely known outside the East Asian countries that produce it, ramie is lightweight, silky and made for summer.
8. **Sisal:** Lustrous and creamy white, sisal fibre measures up to 1 m in length, with a diameter of 200 to 400 microns. It is a coarse, hard fibre unsuitable for textiles or fabrics. But it is strong, durable and stretchable, does not absorb moisture easily, resists saltwater deterioration, and has a fine surface texture that accepts a wide range of dyes. Too coarse for clothing and upholstery, sisal is replacing glass fibres in composite materials used to make cars and furniture.

2.ANIMAL FIBRES

1. **Alpaca:** It is partly hollow, from 20 to 70 microns in diameter and comes in 22 natural colors. It is light, stronger than sheep's wool, and provides excellent insulation. Huacayo alpacas produce soft, dense, short fibers, while the fleece of the rarer sure is lustrous, silky and straight. Alpaca blends well with wool, mohair and silk. Soft and dense, or lustrous and silky, alpaca is used to make high-end luxury fabrics and outdoor sports clothing.
2. **Angora:** The silky white hair of the angora is a hollow fiber classed as wool. With a diameter of 14-16 microns, it is one of the silkiest animal fibers. Angora wool is very soft to the touch, thanks to the low relief of its cuticle scales. Fine, silky and exceptionally soft to the touch, the wool of the Angora rabbit is used in high quality knitwear.
3. **Camel**: The fine down fiber of the Bactrian camel averages around 20 microns in diameter and varies in length from 2.5 to 12.5 cm. Baby camel hair, which can measure as little as 16 microns (on a par with fine cashmere), is the softest and most prized. Owing to its quality and scarcity, camelhair is used in luxury textiles. The best quality camel yarn is spun on drop spindles by women in nomadic households of Mongolia and Inner Mongolia, China.
4. **ashmere:** US standards set an average fiber diameter for cashmere of no more than 19 microns, and top quality fiber is just 14. It has natural crimp, allowing it to be spun into fine, lightweight fabrics. Cashmere has small air spaces between the fibers, which makes it warm without weight, while thin cuticle cells on the fiber surface make it smooth and lustrous. Its luxurious, rare and expensive: the wool of six kashmir goats is enough to make just one cashmere sports jacket.

5. **Mohair:** Light and insulating, its tensile strength is significantly higher than that of merino wool. Like wool, mohair has surface scales, but they are thinner, making it smooth to the touch. Light reflected from the surface gives mohair a characteristic lustre. Thin surface scales make mohair smooth to touch, while light reflected from its surface gives it a characteristic lustre.
6. **Silk:** its filament is a continuous thread of great tensile strength measuring from 500 to 1 500 meters in length, with a diameter of 10-13 microns. In woven silk, the fibre's triangular structure acts as a prism that refracts light, giving silk cloth its highly prized "natural shimmer". It has good absorbency, low conductivity and dyes easily. Developed in ancient China, where its use was reserved for royalty, silk remains the "queen of fabrics".

7. **Wool:** It has natural crispiness and scale patterns that make it easy to spin. Fabrics made from wool have greater bulk than other textiles, provide better insulation and are resilient, elastic and durable. Fibre diameter ranges from 16 microns in superfine merino wool (similar to cashmere) to more than 40 microns in coarse hairy wools. Limited supply and exceptional characteristics have made wool the world's premier textile fibre.

MANUFACTURING PROCESS

Suitable manufacturing process must be utilized for transformation of the basic materials to the final shape without causing any defect in the product. For the proper fabrication selection process with biodegradable polymer related composite, design and manufacturing engineer focuses on a number of criteria, including desired properties, size and shape of the resultant composites, processing characteristics of raw materials, production speed and the manufacturing cost. For small to medium sized components, injection and compression moulding are preferred because of their simplicity and fast processing cycle. However, for large structures, open moulding and autoclave process typically manufacture them.

In a study involving mechanical characteristics of unidirectional sisal / glass fiber reinforced hybrid polyester composites, hand lay-up technique was used for the creation of composites.In processing natural and wood fiber composites , Thermoset mat compression moulding, and Thermoset injection moulding were adapted for the production of green composites. In Mat compression process, a fiber mat is used which was made of natural fibers. In the compression moulding, the mat is sprayed, with resin and compressed into its final contour in a hot tool; with the use of air permeability, the parts could be covered easily in a vacuum covering process. In Analysis of the deformability of flax fiber non-woven fabrics, Resin transfer moulding process (RTM) was used for composite production. It’s one of the main manufacturing process to produce composite parts for the transport industries. It is an increasingly common form of moulding using liquid composites. It’s primarily used to mould components with large surface areas, complex shape and smooth finishing

RESIN

The resins that are used in fiber reinforced composites can also be referred to as 'polymers'. All polymers exhibit an important common property in that they are composed of long chain-like molecules consisting of many simple repeating units. Man-made polymers are generally called 'synthetic resins' or simply 'resins'. Polymers can be classified under two types, 'thermoplastic' and 'thermosetting', according to the effect of heat on their properties. There are three types of resins used in the composite material industry i.e. Epoxy Resin, Polyester resin Orth phthalic Is phthalic Phenolic, Vinyl ester resin and Epoxy. Most of industrial applications of epoxy resin react with a curing cross link agent known as a hardener.

FILLER

Fillers are particles added to material (plastics, composite material, concrete) to lower the consumption of more expensive binder material or to better some properties of the mixtured material.. Among the 21 most important fillers, calcium carbonate holds the largest market volume and is mainly used in the plastics sector. For modifying the chemical and physical properties of the matrix polymers to reduce material costs, improve processability and to improve product performance. Filler forms the addition strength to the mechanical and thermal properties of the composite material. In this filler silicon carbide (SIC) is one of the fillers available. The silicon carbide when used as reinforcement. It will increase the properties like young’s modulus, ultimate tensile strength, tensile strength, hardness of the composite materials.

MECHANICAL PROPERTIES

The kenaf, jute, and hemp yarns that were to produce the woven fabrics were prepared. The EpoxAmite 100 series resin was selected as the polymer matrix, and it was mixed with a hardener in a ratio of 3:1 to form the binder for the composite preparation. For tensile testing, dog bone specimen used using a Dremel 4000 tool and it was performed using a 100 kN universal testing machine. Results indicate that the incorporation of a high strength kenaf fibre with the jute and hemp fibers enhanced the ability of the interwoven hybrid composites to resist breaks and deformation under a tensile load, in comparison with the individually woven composites .

Sisal plants

Sisal plants were prepared. Some portions of cleaned fibers were soaked in 10 wt.% $NaHCO_3$ solution for 24 h, 120 h and 240 h at room temperature, then washed with distilled water and dried in an oven at 40C for 24 h. Tensile test was conducted in UTM . It is possible to observe that the values of both Young's modulus and tensile strength increase with increasing the treatment time up to 120 h. After 120 h of treatment, Young's modulus keeps increasing whereas tensile strength of the treated fibers begun to decrease. This may be due to degradation phenomena which occur if the treatment time is too long

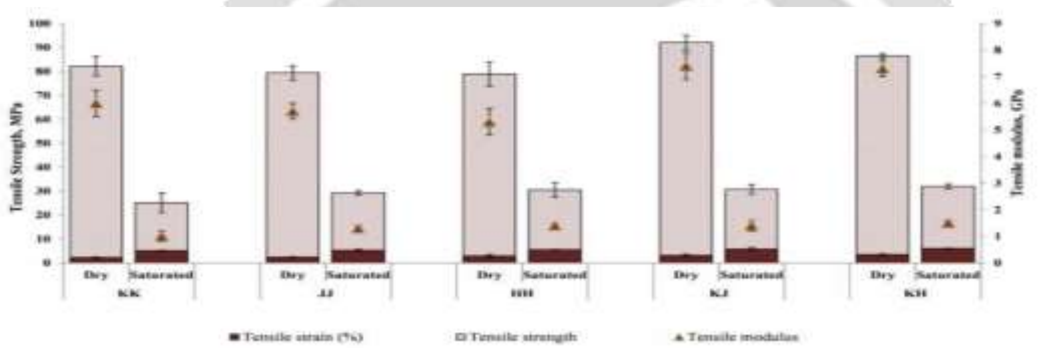

Fig2-Tensile properties of various woven composites in dry and saturated condition

Agricultural fibers

Agricultural fibers retrieved after the crops harvesting called agro fibers. Agro-fibers are bonded with bioplastics called Agro-Plastics. Prototypes are made for Trash ell, Plant Culture. It is bonded with a bio-based epoxy resin through a closed molding process. Plant culture is composed of agro-fibres compounded by a bio-based thermoplastic matrix (PLA bioplastic). Test was conducted on Uni-axis tensile test with the same specimen size. The E-Modulus and tensile strength properties are described in the Fig 2. From the figures, it is clear that Plant Culture has shown the highest performance in comparison to others

Two natural fibres extracted from fruit and bast (ramie) were mechanically characterized. A commercial grade of PCL (Cape 6500) used as matrix. Fibres were treated in a sodium hydroxide solution (5%w) for 4 h at room temperature. 10, 20 and 30 wt.% amounts of natural fibres were tested on a Zwick/Roell Z010 equipped with a 200 N load cell. Results reported that the addition of ramie fibres results in a significant increase in both tensile strength and Young’s modulus of the composites compared to the neat matrix. A slightly different behavior is presented by borassus fibres that did not cause an improvement of the strength over that of neat PCL

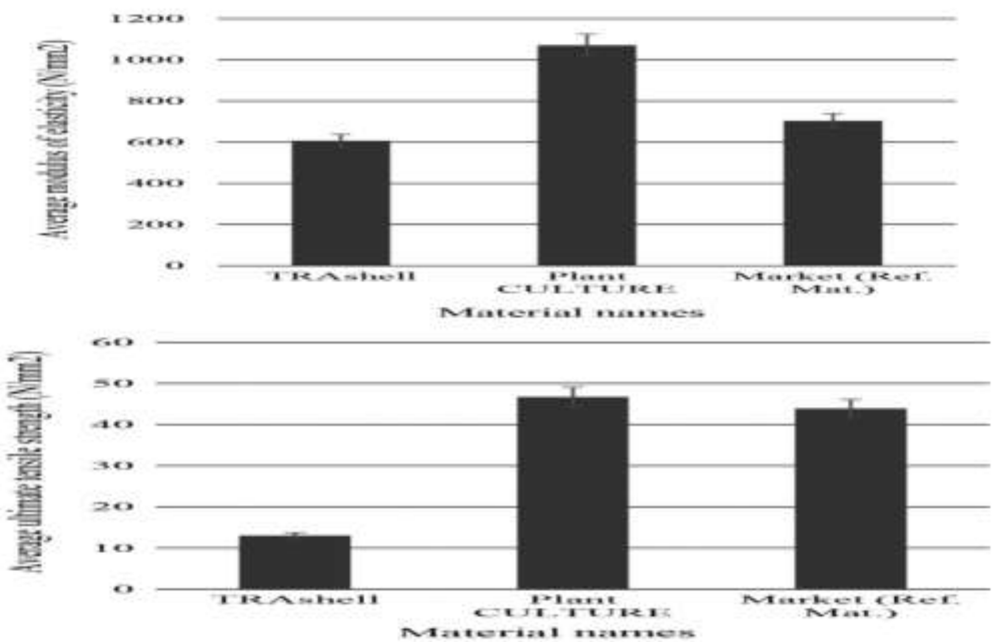

Fig 3- Comparison of Composite Materials- Ultimate strength and Elastic modulus

Fully bio-based thermoplastic composites are manufactured with bio-based polyethylene (85%) (From sugarcane) and short fibre coming from Cortaderia selloana (CS) wastes. Fibres were in the 1-4mm range. Cortaderia selloana fibers treated in a 15 wt% NaOH solution. Tensile and flexural properties of the different samples of bio- HDPE/CS were measured with a universal test machine with a load cell of 5 kN. From results (Fig 4) the fibre content increases, both the tensile and flexural modulus increase

Epoxy matrix was mixed with a mechanical stirrer with 2.5, 5, 10 wt% of basalt powder respectively to the total weight. The compositions were mixed with curing agent Z1[tri ethylene .The epoxy composites were fabricated in a mold using hand layup method. Tensile mechanical properties were measured with INSTRON 4481 universal testing machine with a load cell of 50 kN. In all cases from results found that basalt filler introduction led to an increase of the elasticity modulus break. Introduction of higher amounts of the powder may cause formation of (defects) in epoxy matrix

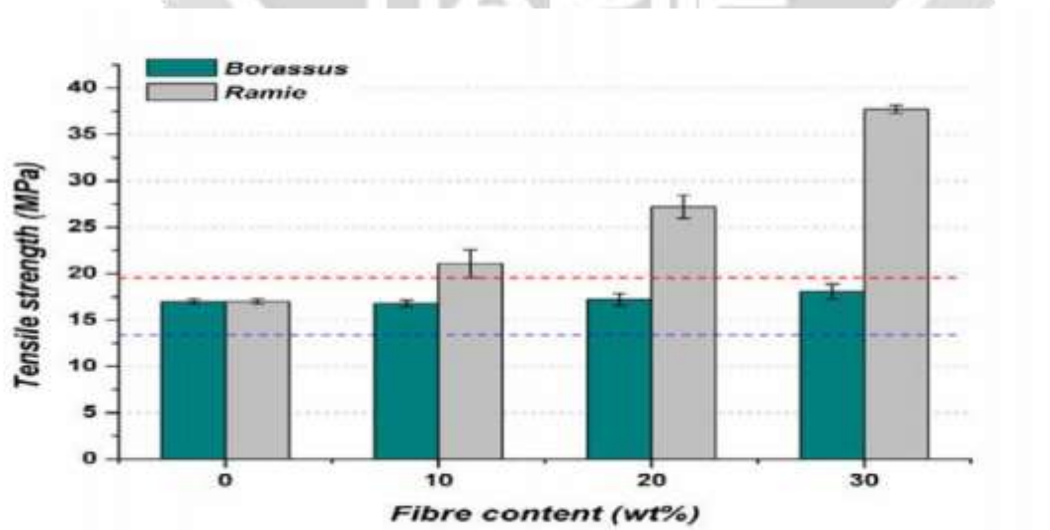

Fig 4 - Tensile strength for composites reinforced with borassus and ramie fibres

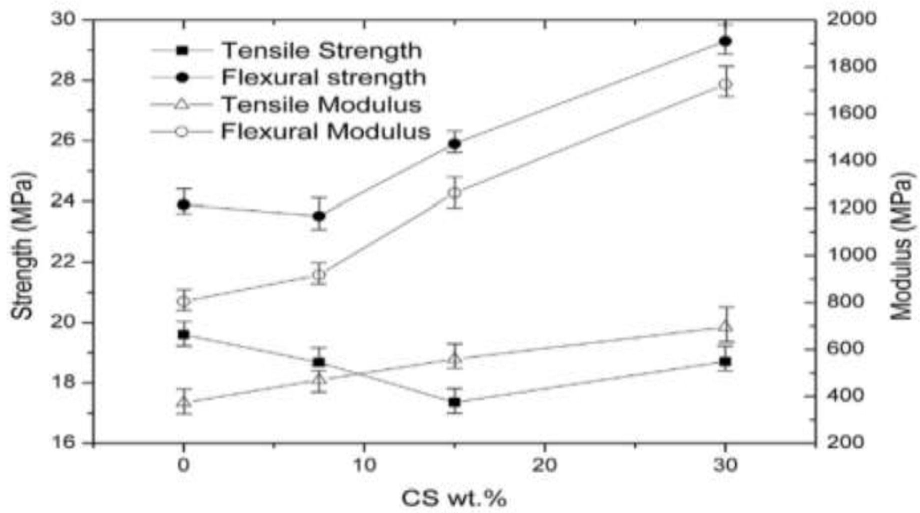

Fig-5 Mechanical properties of bio-HDPE/CS composites in terms of the wt% of Cortaderia

Cement masonry blocks reinforced with lechuguilla natural fibres that were lightened with polyethylene terephthalate. A concrete mix was designed for a target compressive strength of 16 MPa at 28 days. Masonry concrete blocks were produced for two different fiber lengths (25 and 50 mm) and with fiber contents of 0.25%, 0.50%, 0.75% and 1.0%. Based on the obtained results, it was found that as the aspect ratio decreases the compressive strength increases

Natural Hemp Fibres

Natural Hemp Fibres are taken. The short length hemp fibers treated with 5% NaOH (THF) were sandwiched in bisphenol A-aniline based benzocaine (BA-a) to form the resin-fibre-resin composite. It was detected that with increase of fiber content from 0 to 25 volume % Tensile strength gradually increases. Addition of 25 vol % THF doubles the Tensile Strength of composite as compared to poly(BA-a)

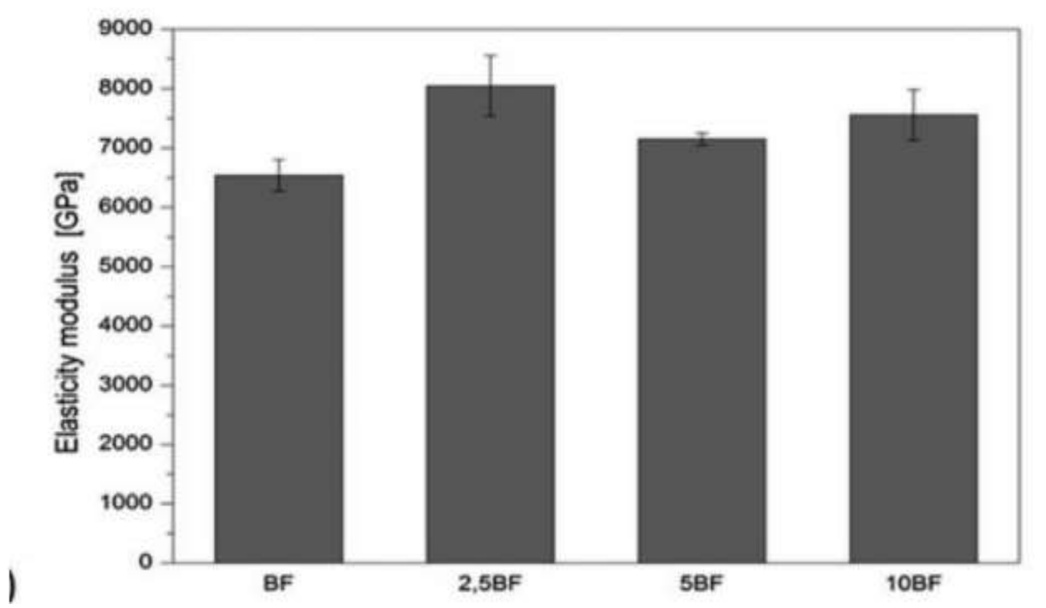

Fig-6 Mechanical properties of composites

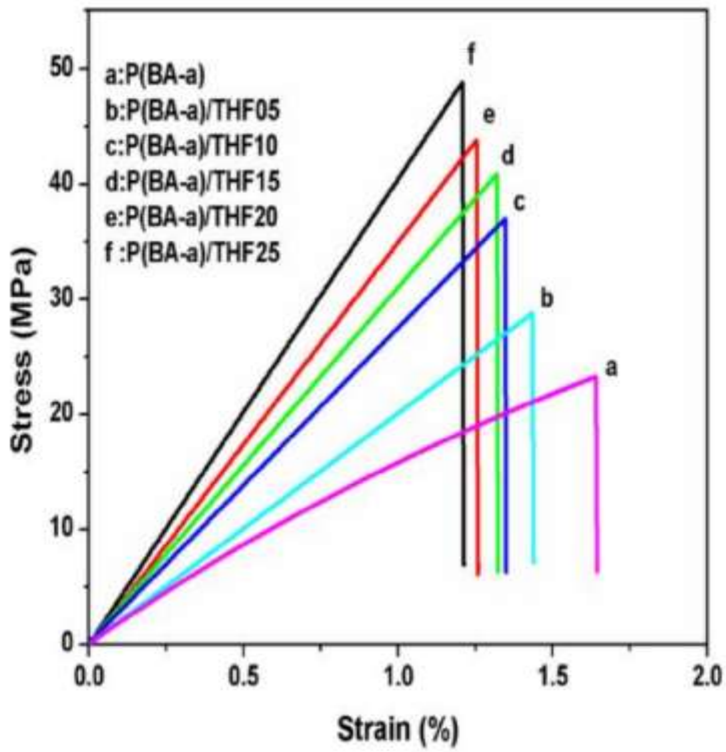

Fig-7 Stress strain for THF content

Basalt fiber (BF)

Basalt fiber (BF) was used to reinforce polylactide (PLA) to obtain new composites with potential structural or engineering applications. The tensile strength and modulus increase with increasing BF loadings. 20 wt% BF can increase the strength and modulus by about 30% and 47% respectively

Composites with different volume fractions (30, 40 and 50 volume %) were confectioned by laying the fibres in a steel mold and pouring liquid resin epoxy under pressure of 3 MPa. The specimens were dried for 24 h at room temperature and then tested in a universal Instron tensile testing machine. From results the presence of eucalyptus fibres did not affect the tensile strength but increased the elastic modulus of epoxy matrix composites. Indeed, the value of elastic modulus increased approximately 50% for epoxy matrix composites

Sisal Fibres

Sisal Fibres are taken to study the effect of the alkalinity of pore solution on fibre degradation metakaolin (MK) with 10 wt% (MK10) and 30 wt% (MK30). The specimens were demolded after 24 h and immersed in pH-saturated water at 23±2 °C for 28 days prior to accelerate aging treatment. Stress–strain curves obtained by uni-axial tensile testing of selected sisal fibres. It can be seen that the tensile strength of the embedded fiber in MK30 after 5 wetting and drying cycles is slightly higher than that of a raw fiber. It is caused by the removal of non-cellulosic materials and impurities.

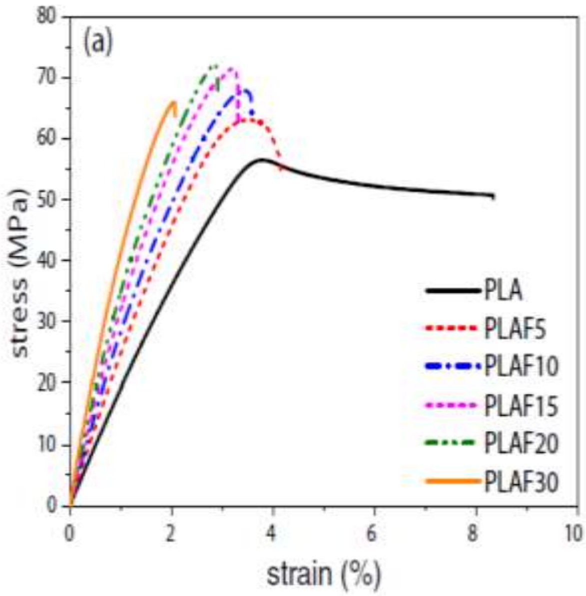

Fig-8 Stress Strain curve for PLA & PLABF

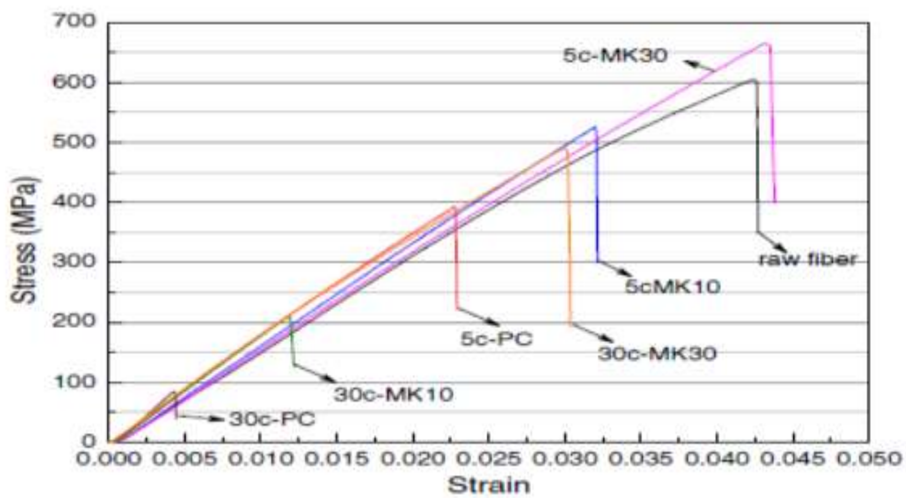

Fig-9 Stress–strain curve of tensile test on sisal fibres

Sisal fibres are prepared. Sisal fibres are treated by Hornification, Alkali treatment, Polymer impregnation, Hybrid treatment. The tensile tests were performed in an electromechanical testing machine with a load cell of 1 kN. For alkali treatments the tensile strength of sisal fiber was improved by 32%. Reason of the increment in the tensile strength and elongation is the removal of non-cellulosic materials and impurities. The treatment with polymer and hybrid increased 50 % and 60 % tensile strength

Natural fibre

Natural fibre composite plates are made from hemp, flax and jute fibres are subjected to pure compression. Epoxy resin is used for composition. The buckling and post-buckling responses are stable and the final condition is reached in a predictable and stable manner .From Fig 10 Jute have high tensile strength and Flax have high elastic modulus. From results this natural fibre composite sections can be used in light structural applications such as in the residential and light commercial market

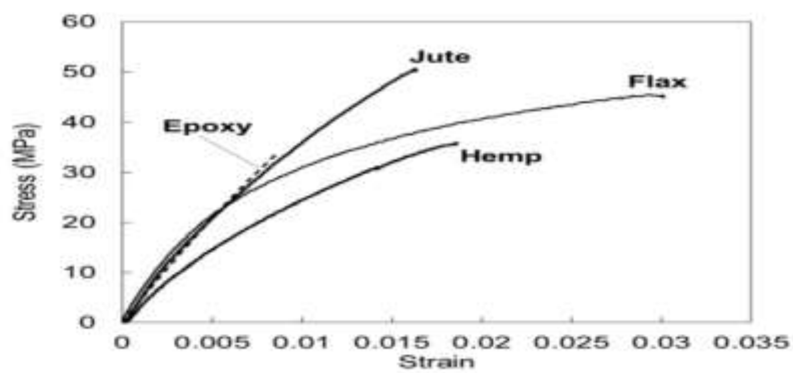

Fig-10 Stress Strain Curve for Fibre composites

Short fibres

Short fibres (1-4mm) from Cortaderia selloana (CS) wastes are collected. These fibres are treated with bio-based polyethylene compounds like maleic anhydride, hydrophobic silane, Sodium hydroxide and alkali treatment. Mechanical properties evaluated by impact and tensile tests. Addition of fibre (30%weight) increases the stiffness while Tensile strength not affected but gradually increased. But elastic modulus increased twice for 15-20% fibre content Coir fibres are taken for alkali treatment. These coir fibres are reinforced with epoxy [CFRE]. Then CFRE treated with 5% weight NaOH solution for 30 min at 20 C. Mechanical properties of CFRE were determined by tensile test on the Instron 5567 machine. Alkali treatment improved the tensile and flexural properties. From results found that 16.7% and 17.8% growth in flexural and tensile strength respectively

Coir fibres

Coir fibres are taken from husk as hydrated and dehydrated form. Tensile test was carried out on horizontal environmental micromechanical tester (max 450g). From results (Fig 12) that dry fibres have higher strength than the wet fibres. Fibre diameter is larger in Wet specimen

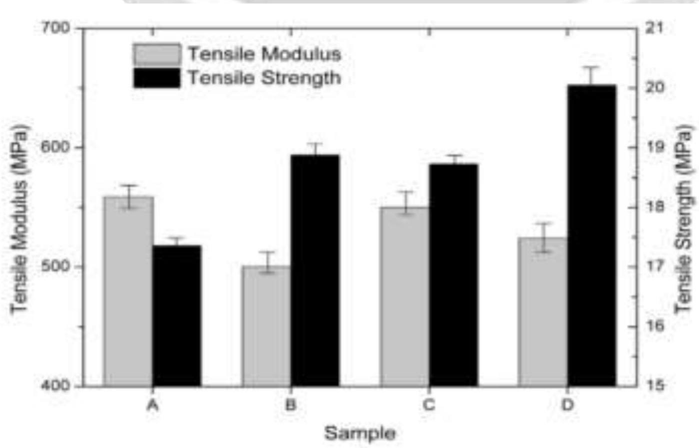

Fig -11 Tensile Properties

From herbaceous plants banana fibre is obtained. Flax fibre is obtained from family linaceae. Epoxy and Hardener is used in the ratio of 9:1. Fabrication process is made by sandwich method. By hand layup method one layer of banana fibre is sandwiched between two flax fibre layers. The result (Fig 13) shows that hybrid composite has better properties than other single fibre glass reinforced composites under flexural and impact test. It is found that the hybrid composite have high strength than the single fibre composites.

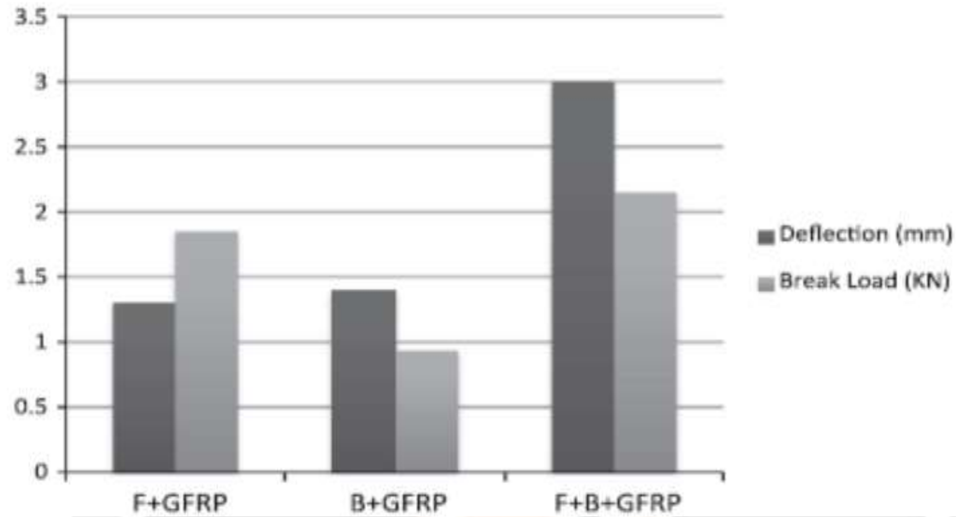

Fig-12 Comparison of Break Load, Maximum Deflection

Banana fibres

Banana fibres are obtained from plant. Polypropylene (PP) and maleic anhydride grafted polypropylene (MAPP) are mixed in the weight ratio of 95% and 5% respectively. Composites are prepared in the ratio of 70:30 for PP and fibre respectively. Tensile test was conducted on Universal Testing Machine (5kN) for five specimens at temperature of 25°C. From results (Fig 14) that PP/Banana yarn composite have the highest improvement on tensile strength, which is 294% from others

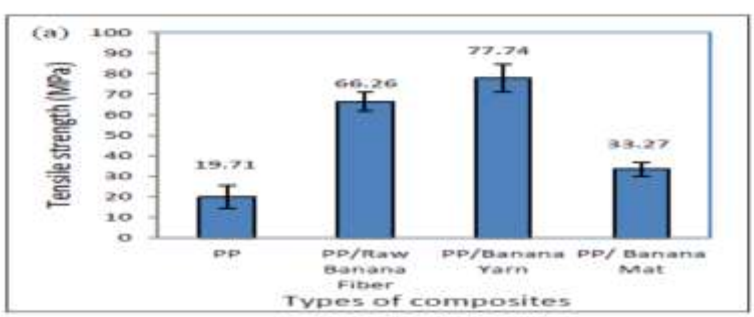

Fig-13 Bar chart of Tensile strength

THERMAL PROPERTIES

Thermal insulated materials based on natural fibres are currently high on construction market. Hemp-based insulated materials are taken. These samples should not contain more than 20% of weight content. Specimen made by bi-component bonding method (air-lay) with the addition of 15% of polyester bi-component fibres. From result it is found that Increase in Density will decreases the Thermal Conductivity. Coir fibres are prepared and washed in water. Then it kept in 1.6 mol/L NaOH solution for 48 Hours. Polypropylene (PP) is used as reagent with a density of 0.9 g/cm3. Using thermo gravimetric analysis (TGA) thermal stability was evaluated. From results show that the alkali treatment enhances the thermal stability of the fibres from 324/449°C to 331/474°C,by elimination of non-cellulosic compounds on the fibres surface.

CONCLUSION

Natural fiber reinforced thermoset composites are the best alternative materials for the synthetic fiber reinforced composites due to their properties such as low density, less expensive, high flexibility, abundant availability, and eco-friendly nature. Even though natural fibers are with many advantages, it will be of no use if the composites are not fabricated without surface modification of the fibers, good selection of fiber, and the matrix and proper combination of the constituents such as weight fraction, size, and orientation of the fibers. Using natural fibers as reinforcement in the thermosets will introduce the positive effect on the mechanical properties of the thermosets. Composites with the high.

In terms of future development and aside from issues concerning polymer cost and processing, there are also challenges with use of plant fibres that have to be considered. For example, fibre properties depend on a number of factors such as plant source, plant age, processing techniques, geographic origin and climate. Moisture sorption and desorption over time can also lead to reduced strength and deboning from a polymer matrix. As discussed in this chapter, the use of fibre treatments can improve composite mechanical properties and can also enhance resistance to water uptake. In addition, most fibres cannot withstand temperatures much above 175ëC for long periods, limiting their use in terms of processing with certain polymers. Practical processes for handling plant fibres in extrusion and injection molding processes, without losing the advantages provided by these fibres, are also needed if the full potential of plant fibre bio composites is to be realized in the future.

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6 Natural Fibre Reinforced Polymer Composite Materials - A Review

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7 Polymer matrix-natural fiber composites: An overview T.G. Yashas Gowda1, M.R. Sanjay2, K. Subrahmanya Bhat3*, P. Madhu1, P. Senthamaraikannan4 and B. Yogesha1

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9 THERMAL CONDUCTIVITY BEHAVIOR OF NATURAL FIBER-REINFORCED COMPOSITES Ryosuke Osugi1*, Hitoshi Takagi2, Ke Liu1, and Yusuke Gennai1

10 Fabrication and Effect of Immersion in Various Solutions on Mechanical Properties of Pultruded Kenaf Fiber Composites: A Review A.M. Fairuz1, S.M. Sapuan2, N.M. Marliana3 and J. Sahari4

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12 A REVIEW ON MECHANICAL AND THERMAL PROPERTIES OF NATURAL FIBER REINFORCED HYBRID COMPOSITES Santhosh S 1, Bhanuprakash N 2

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14 Experimental Study on Optimization of Thermal Properties of Natural Fibre Reinforcement Polymer Composites Ramesh Chandra Mohapatra

15 Biodegradablepolymercomposites fromnaturalfibres D P L A C K E T T , Risù National Laboratory, Denmark

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