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NATURAL FIBRE COMPOSITES: A REVIEW ON FLAX FIBRES

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Abstract: *In the composite industry, generally glass and carbon fibres are most widely used materials because of their high strength to weight ratio. On the other hand, in recent years, the use of natural fibres as reinforcement in composites have shown some esteem due to their properties such as light weight, low cost, recyclability, biodegradability and an increasing requirement for developing sustainable materials. Some of these natural fibres, such as jute, flax is cost-effective and can be much more in demand due to their specific mechanical properties comparable to the glass fibres. This study focuses on natural fibre composites (NFCs) in which polymeric resins are used as matrix materials. NFCs materials have at least one primary component originated from a biological source. Here, fundamentals of NFC materials are presented according to the reinforcement preforms, matrix resins, which are thermosets or thermoplastics, composite manufacturing techniques and characterization. Since NFCs based on renewable resources can provide feasible low-cost structural components and eco-friendly alternatives to conventional structural materials for many applications such as equipment housings, roofing and in large diameter piping. This review is especially carried out in more detail on the flax fibres which are the recently emerged offers for automotive industry. Additionally, fibre/matrix interfaces of these studies are reported.*

Key words: *NFCs, green composites, flax, mechanical properties, automotive.*

1. INTRODUCTION

Natural fibre composites (NFCs) are composing from reinforced fibres which are derived from renewable and carbon dioxide neutral resources such as wood or plants. NFC composites are generally used where a moderate strength are required i.e. housings, roofing, in large diameter piping for low-cost housing [1]. Natural materials have some advantages such as they are renewable, reasonably cheap, biodegradable and ecologically freindly. More recently sustainable mobility is also important; for instance, European Parliament and the Council reduced the deposition fraction of a vehicle from 15% (2005) to 5% (2015). However, natural fibres have disadvantages too; for example, they show variations in both fibre geometry and in physical properties, have lower mechanical properties, poor interfacial adhesion and incompatibility with hydrophobic matrix resin systems [2]. For this reason, researchers are willing to improve those advantages of NFCs on the reinforced composites such as in automotive industry and other applications. This can be seen in some studies [3],[4],[5] where natural fibres such as sisal,bamboo, jute, flax and wool were used to attain good tensile properties comparable to glass fibres.

This review emphasizes on NFCs in which polymeric resins are used as matrix materials. As is known, NFCs materials have at least one major component derived from a biological origin. The natural fbres can be used as the reinforcement fibres either long (i.e. flax, hemp, kenaf, jute, ramie and sisal) or short (i.e. wood, wool,) from the fibre processing and/or recycled fibres [6]. The matrix materials can be derived from biomaterials such as various epoxidized plant oils and soy protein [7]. The major ones of the NFC materials are made from a combination of natural fibres and polymeric matrices.

NFCs can be produced with traditional composite fabrication methods such as resin transfer moulding (RTM), vacuum infusion, compression moulding, a direct extrusion and compounding, injection moulding. These different manufacturing techniques can affect various properties on the resulted composite materials. The properties of NFCs, thus, can be modified for various types of applications by choosing appropriate fibres, matrix resins (thermosets or thermoplastics), additives and production method. NFCs can replace the traditional application areas of fibreglass reinforced plastics (FRP) and thermoplastic composites (TPC) by choosing the proper natural reinforcement fibre and its matrix resin. The most common thermoset resins are epoxy, polyester, vinylester, polyamide, polyurethane and phenolics (see Table 1).

Table 1: *Unfilled thermosetting resin properties [8]*

Resin	Density (g/cm^3)	Tensile Modulus (GPa)	Tensile Strength (MPa)
Epoxy	1.2-1.4	2.5-5.0	50-110
Phenolic	1.2-1.4	2.7-4.1	35-60
Polyester	1.1-1.4	1.6-4.1	35-95
Acrylated epoxidized soybean oil/styrene	1.0-1.2	1.0-1.6	15-21

Lately, NFCs are fabricated with bio-based thermosetting resins such as soybean triglycerids. Petrovic et al. 2004 [9] and O'Donnell et al. [10] studied natural fibre/acrylated epoxidized soybean oil composites which are known as bio-based green composites. However, one of the disadvantages may be their component life which may be lower if compared to FRP components. Therefore, it is necessary to obtain better component life, performance and sustainable materials in the future studies. For example, in automotive components, natural fibres can be chosen such as flax, ramie as a replacement of glass fibres. Some of these NFCs i.e. flax and bamboo fibre composites are introduced at the below sections.

2. FLAX FIBRE

As mentioned earlier, natural fibres are used to replace glass fibres [11],[12]; for instance it is estimated that approximately 830,000 tonnes of natural fibres will be consumed by 2020 and hence the total reinforcement materials may go up to 28% [13]. As they are cost effective with low density they will find various places for many engineering applications in the future. Before moving to flax fibre composites, a summary on flax fibre is given below.

Flax is a plant fibre which belongs to *linaceae family* and is one of the widely utilised natural fibres. Records from Babylonia and Anatolia from 3000 BC show that flax was cultivated in Ancient Egypt for its seeds and for linseed oil; it is also one of the oldest to be extracted, spun and woven into textiles where was found in graves in Egypt dating back to 5000 BC [14]. Flax fibres are produced in the stems of flax bast plant and are a cellulose polymer. As its structure is more crystalline than cotton it is therefore stronger too. Flax is also stiffer to handle and is more easily wrinkled than cotton. Length of a flax plant ranges up to 100 cm which has strong fibres along its stem with average fibre diameter 10-25 µm [15]. The micro-structure of a flax fibre is complex due to the hierarchical organisation at different length scale and different materials present in variable proportions (Fig.1). From the Fig.1, it can be seen that the thickest cell wall is S2. This wall contains numerous crystalline cellulose micro-fibrils and amorphous hemicellulose which are oriented at 10º with the fibre axis that gives the high tensile strength to the flax [16].

Flax fibre consists of cellulose, hemicelluloses, wax, lignin and pectin in different quantities where reported by many authors [17], [18]. This variation of proportions in the constituents of flax fibres is due to the plant variety, agriculture variables i.e. soil quantity, weathering conditions, level of plant maturity, quality of retting process [19]. However, it is well known that flax is rich in cellulose for about 70% of the total chemical composition and this makes it possible to be used as reinforcement in composites. As for the natural fibres such as flax, the main disadvantage is their hydrophilic nature which lowers the compatibility with hydrophobic polymeric matrices during the composite production. On the other hand, natural fibres have low mechanical properties; flax fibres do show better mechanical properties than the most natural ones; especially when retting is done to improve its mechanical properties. Flax looks much agnate to cotton fibre except in pigment intensity [20].

2.1. Flax Fibre Composites

Flax fibre reinforced composites are not only considered in the form of monofilament configuration [21], [22] they can be also processed into mats [23], [24], rovings [25], [26], yarns [27], and fabrics [28], [29] in composites. A series of manufacturing techniques have been developed to produce composites, such as film stacking [24], hand lay-up [5], vacuum infusion, filament winding [27], compression moulding [21], [22], resin transfer moulding (RTM) [23], [26], injection moulding [21] and pultrusion [25].

Flax fibre composites are being used such as in the forms of panels, tubes, sandwich plates, to replace the wooden fittings, fixtures, furniture, and noise insulating panels in the last decade. There is also an increasing demand from automotive companies for materials both with sound reduction capability and lower weight for fuel efficiency. NFCs have excellent sound absorbing efficiency and are more shatter resistant and have better energy management features than glass fibre reinforced composites. In automotive parts, bio-composites not only reduce the mass of the component but also lower the energy needed for production by 80% [30]. Although flax fibres have potential to replace glass fibres as reinforcement in composite, their main disadvantage is the variability in their properties. Environmental effects such as high relative humidity can degrade the tensile properties of these fibres. However, an appropriate chemical curing, i.e. Silane (Si), can increase the breaking strength and strain of the flax fibres (see Fig.2) [31].

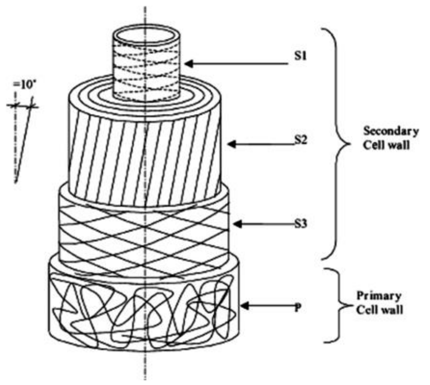

Fig.1: *Flax fibre cell [16]*

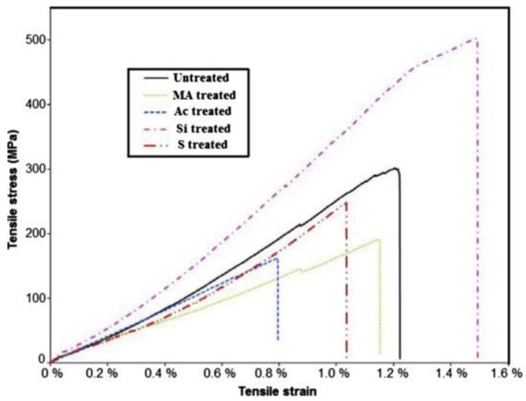

Fig.2: *Stress-strain diagram of untreated and chemical treated flax fibres [31]*

Also, the tensile properties of flax fibres are not consistent along its length. Their tensile strength and modulus can decrease with an increase in fibre length, fibre diameter and gauge length. Therefore, because of flax fibres at the mid-span and tip in the stem have high content of cellulose [32], it is suggested to use as raw materials for flax fibre reinforced composites.

Before using flax fibre as a reinforced material, another important object is fibre surface condition which is critical for interfacial bond between fibre and matrix. Hence, alkali treatment is beneficial to clean the fibre surface, modify the chemistry on the surface, lower the moisture uptake and increase the surface roughness prior to the composite production [5] (see Fig.3. and Fig.4.). It was observed that dewaxed flax fibre reinforced composites exhibited better impact energy absorption capability when compared to untreated flax fibre reinforced composites.

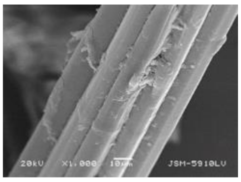

Fig.3: *Dewaxed flax fibre (X1000) [5]*

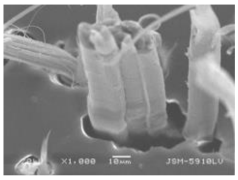

Fig.4: *Izod impact test of untreated flax fibre reinforced composite (X1000) [5]*

3. GREEN COMPOSITES FOR AUTOMOTIVE INDUSTRY

Automotive industry has been pioneer for the long NFCs. Comparing to glass, natural fibres with low density reduces vehicle weight and consequently lowers fuel consumption. It is estimated that no more than 50 kg of natural fibres can be used in a car. This corresponds to a reduction of about 10 kg if glass fibre composites are replaced with natural fibre composites in an automobile. If the weight of a car can be reduced by 10 to 20 kg, the effect on the environment will be significant. The European car production is about 55000000 cars/year. This indicates that more or less 1000000 metric tons of natural fibre materials are targeted for the consumption in the automotive industry.

Today, beside flax, other plant-based fibres i.e. hemp, sisal, jute are also used to produce various parts in automotives; for example, door and trunk panels, headliners, floor panels, dashboards, insulations. NFCs can also be formed in various degrees of strength and rigidity.

Compression moulding is one of the simple production methods for the automotive industry and can take advantage of non-woven mats that can be impregnated with thermoplastics or thermosets. Recently, the automotive industry has also shown a lot of interest in injection mould NFCs for lower cost interior or exterior panels. Germany is the leader in the green composites and the German auto manufacturers have taken the initiative to introduce NFCs for interior and exterior applications. As am example, the first commercial inner door panel was made of 35% Baypreg F semi-rigid (PUR) elastomer from Bayer and 65% of a blend of flax, hemp and sisal [33].

4. CONCLUSIONS

NFCs with an appropriate matrices exhibit promising mechanical properties such as in flax fibre reinforced composites. A major limitation of using flax fibres as reinforcement in composites is their inconsistency. However, this may overcome if appropriate alkali treatment is carried out prior to composite production; therefore, a good fibre/matrix interfacial bonding can be achieved and thereby the tensile properties can be improved. Also, the selection of suitable manufacturing process and physical/chemical modification is very important, i.e. NaOH for bleaching and/or cleaning the surface of the plant fibre to improve its mechanical properties of the flax composites. Flax composites have the potential to be the next generation materials for structural application for automotive industry and for other consumer applications. Imminent studies on flax composites can be attentive to understand environmental assessment, durability, improving the mechanical properties and moisture resistance. We also believe that, novel manufacturing processes and surface modification methods can be developed in the future.

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