

Composite materials manufacturing using textile inserts with natural origins fibres

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Abstract. The main activities described in this article are carried out during the experimental phase of the research on composite materials manufacturing using textile inserts with natural origins fibres, oriented towards the manufacturing of composite materials samples. The objective of the research is to develop new fully or partially biodegradable composite materials by using new natural fibres and those recovered from various textile wastes. Thus, the research aims to obtain some composites with matrix of various types of polymeric materials and the reinforcement phase of textile materials so that the resulting products to be biodegradable. The textile inserts used as reinforcement are ecological, non-toxic and biodegradable and they contain bast fibres (flax, hemp, jute, divided or in combination), which can replace fibres of glass commonly used in polymeric composites. The purpose of the research is to obtain composite materials with high-structural, thermo-mechanical and/or tribological performances, according to ecological norms and international requirements in order to replace the existing classical materials, setting up current, innovative and high performance solutions, for applications in top areas such as automotive industry and not only.

1. Introduction

Since about three decades there has been an increasing interest in environmentally friendly composites, based on natural resources. The development of high-performance composites made from natural resources is increasing worldwide day by day. In this sense, the use of natural fibres for technical composite applications has recently been the subject of intensive research and many studies have previously focused on natural fibres as potential reinforcements in composites. Many researchers have examined and researched the suitability, competitiveness, and capabilities of natural fibres embedded in polymeric matrices [1–10]. The researchers have been focused on the effect of the fibre surface modifications as well as manufacturing processes in improving fibre/polymer compatibility [1–4]. On the other hand, some researchers studied and compared between different natural fibre composites and their stability in various applications [5–10]. The use of composite materials dates from centuries ago, and it all started with natural fibres. During the last decade there has been a renewed interest in the natural fibre as a substitute for glass, motivated by potential advantages of the natural fibre reinforced composites [2,4,7–12].

Due to environment and sustainability regulation in the last decades considerable performance in green technology in the field of materials science through the development of natural fibre reinforced composites could be noticed [2–5,9–12]. Thus, the development of high-performance materials



produced from natural resources expands worldwide. This can be attributed mainly due to their assets compared to the synthetic materials like low cost, low weight, less damage to processing equipment, improved surface finish of moulded parts composite, good mechanical properties, biodegradability, abundant and renewable resources [1–16]. Natural fibres are valuable and versatile resources with multiple advantages [1–12]. Among the several existing natural fibres, increasing attention is being given to the bast fibres (hemp, flax and jute), due to their remarkable properties [1–16].

Based on material type, the market is subsegmented into glass fibre, carbon fibre, aramid fibre and natural fibre [1–10]. Although, the carbon fibres is projected be the most lucrative segment owing to the huge potential for applications in reinforced composites and lightweight materials for various industries, the natural fibres is expected to grow during the forecast period and has the highest potential for investment owing to its various applications and versatility in usage [2,5–12]. Technological advancements in the carbon and aramid fibre moulding processes, adapted for the natural fibres, have created numerous growth opportunities [2,11,12].

The development of natural fibre composites is limited due to several issues: [1–4,10,17,18]

- the thermal degradation of natural fibers could decrease the mechanical properties (toughness and bending strength), result in poor organoleptic properties (odour and colour) and possible production of volatiles at processing time over 200°C (The thermal degradation of natural fibers occurs in two stages: between 220–280°C mass loss is associated with degradation of the hemicelluloses, while between 280–300°C the lignin is lost).
- the high moisture content of natural fibers, especially cellulosic fibers, could lead to poor dimensional stability and process-ability, and porous issues;
- the composites exposed outdoors may bio-degrade by ultraviolet light;
- the dispersion of natural fibers is affected by the strong inter-fiber bonding; and
- the incompatibility between the polymer matrix and the natural fibers properties (hydrophilic and hydrophobic properties of natural fibers and polymers, respectively) which cause poor bonding interaction at interface.

Textiles find their applications as reinforcement in composites [5,15,17,18]. The study of some technologies has revealed that they could be applied on an industrial scale for the economic advantages, performance and simplicity of design [17,18]. Textile fibres are the basic raw material of the textile industry but, at the same time, they are also important material for many other areas of the industry. In the modern period, pre-consumer waste textile materials, like those resulting from technological processes, but also from post-consumer waste, i.e. those collected, have been used to obtain a variety of textile products such as yarns, fabrics, knitwear, nonwovens, beds and so on, products used in many sectors [6–12,17,18]. The fibres resulting from the recovery of waste, which serve to obtain nonwoven products, are used in the form of fibrous layers. These are textile supports, consist of fibre-oriented agglomerations or multidirectional. Practically, all types of fibre, including fibres recovered from reusable materials, can be used as starting materials for technical textiles [18]. Reusable textile materials, also known as textile waste, come primarily from textile processing (spinning, weaving, knitting and so on), fabrication, machining in other textile processing sectors or as a result of physical or moral wear of textile products [18]. Woven structural fabrics are usually constructed with reinforcement tows, strands, or yarns interlocking upon themselves with over/under placement during the weaving process. The more common fabric styles are plain, twill or satin weaves (Figure 1). The plain weave is the most usual and its construction results from each fibre alternating over and then under each intersecting strand.

Textiles have the advantage of mass/strength ratio, reducing the time to achieve, eliminating waste resulting from the production and processing process, a better control of the final shape of the product and superior quality [18]. At the same time, textile materials allow direct control over the material characteristics from the design stage. In the case of textile materials, the architecture is favoured by their extreme deformability being possible to obtain knitted fabrics of special complexity. This feature has made textile materials to be regarded as a possible alternative to the production of preforms for advanced composite materials recently [18]. Textile materials can also have three-dimensional

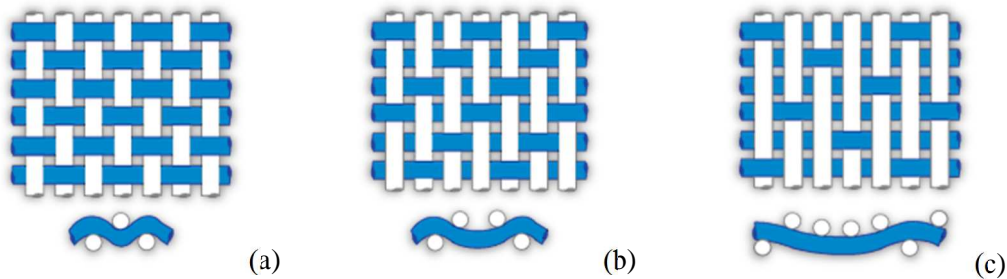


Figure 1. Common textile weaves: (a) plain weave; (b) twill weave; (c) satin weave.

architectures and the production of some of the most complex fittings eliminates the intermediate stages of preforms (with implications over production time and costs) and the possibility of controlling the final shape from the material design stage [2,16,18].

2. Investigations on natural fibres

Three different natural fibres were investigated in the present study: flax, jute and hemp (Figure 2). The flax and jute fabrics were commercially produced for fibre–resin composite fabrications [1–6,14–16]. The hemp fabric was not produced specifically for fibre–resin composite applications, however was recommended as the most appropriate fabric for working with resins by the manufacturer [1–6,14–16].

Natural fibres have complicated structures in microscopic view (Figure 3 & 4). The major constituents of natural fibres (lignocelluloses) are cellulose, hemicellulose, lignin, pectin and ash (Table 1). The percentages of each component vary for each different type of fibre, however, generally, is present around 60–80% cellulose, 5–25% lignin, and until 20% of moisture. The amount of these components affects directly the properties of the fibre, since the hemicellulose is responsible for the moisture absorption, bio– and thermal degradation whereas lignin ensures thermal stability but is responsible for the UV degradation. The chemical composition of commons natural fibres are shown below.

Information about main mechanical properties are shown in the chart below (Table 2) and can be compared to properties of commonly used fibres such glass fibre, aramid fibre and carbon fibre [1–6,10,13–16]. Table 2 reports the main mechanical characteristics of natural fibres, as compared with glass fibres. Unsurprisingly, significant variations are observed, obviously connected to biological

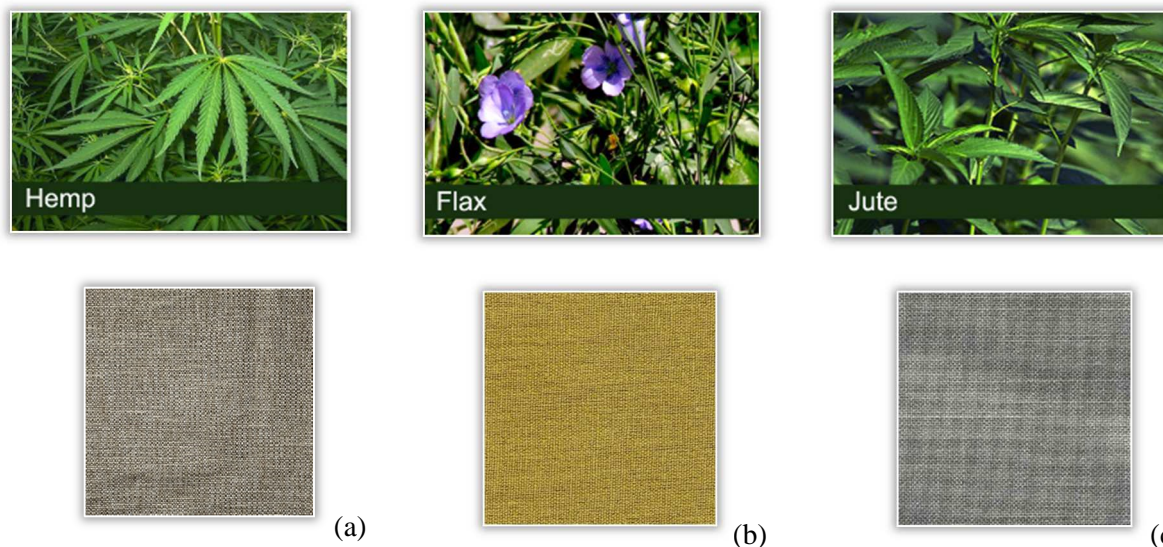


Figure 2. The common natural fibres/bast fibres plants (top) and weave (bottom): (a) hemp; (b) flax; (c) jute.

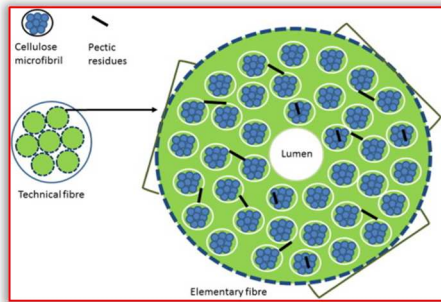


Figure 3. Natural fibres in microscopic view.

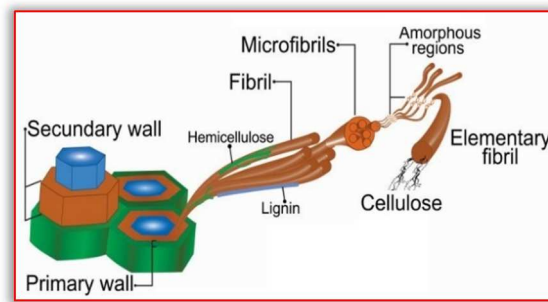


Figure 4. Schematic representation of the molecular structure of the plant cell wall.

differences among plants, climatic history, geographic area, type of cultivation and fibre extraction technology. As a consequence, differences can be found in batches coming from the same area and brands that differ only in the year of production [1–6,10,13–16].

Table 1. The chemical composition of commons natural fibres.

Type of fibre		Cellulose (%)	Lignin (%)	Hemicellulose (%)	Pectin (%)	Ash (%)
Bast fibre	Flax	71	2.2	18.6–20.6	2.3	–
	Jute	45–71.5	12–25	13.6–21	0.2	0.5–2
	Hemp	57–77	3.7–13	14–22.4	0.9	0.8

Table 2. The main mechanical properties of commons fibres.

Fibre		Density (g/cm ³)	Elongation (%)	Tensile strength (MPa)	Young's modulus (GPa)	Moisture absorption (%)
Bast fibres	Jute	1.3–1.46	1.5–1.8	393–800	10–30	12
	Flax	1.4–1.5	1.2–3.2	345–1500	28–80	7
	Hemp	1.48	1.6–3.0	550–900	70	8
Synthetic fibres	E-glass	2.5	2.5–3.0	2000–3500	70	–
	Aramid	1.4	3.3–3.7	3000–3150	63–67	–
	Carbon	1.4	1.4–1.8	4000	230–240	–

It is noticeable that tensile modulus of natural fiber reinforced composites would be higher when all microfibrils are aligned along the fiber's direction, where tensile loading is applied [10,13–16]. The internal structure of natural fibers is contingent upon the age and origin of the plants and climate conditions. [1–6,10,13–16] Moreover, microfibrils are not identical as they are comprised of crystalline and amorphous regions (Figure 4), in which the former one determines the strength of fiber while latter one is relatively soft and formed by irregular molecular chains [10].

3. Experiments on fiber–resin composite plates

Composite textiles with reinforcement materials comprise a wide range of reinforcement material in the form of textile preforms which may be constituted by non–woven, woven or knitted materials. In order to select the optimal technology for preparing textile preforms, it is necessary to consider both the strengths and weaknesses of each technology. Different methods are used to obtain composite structures:

- embedding the reinforcement material (woven textile) into a matrix, which may be either a macromolecular substance or a colloidal solution or suspension with coagulation properties;

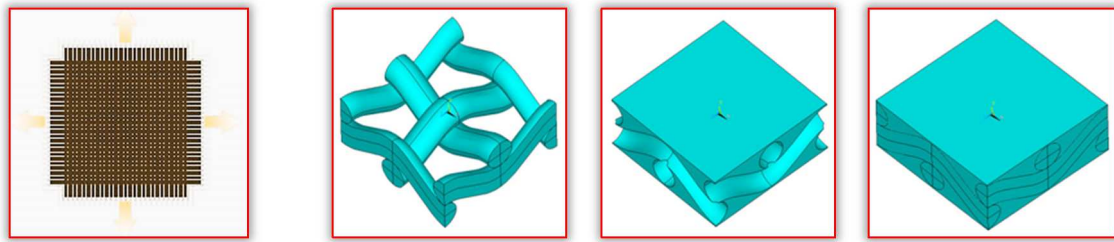


Figure 5. Embedding the reinforcement material (woven textile) into a resin matrix.

— consolidation of the base material by means of curing layers, resulting in a laminate. The textiles are prepared separately and are incorporated into the matrix by one of the following methods:

- simple lay-up process. It is the case of synthetic resin matrices applied in alternating layers of textile layers. The method is used on an industrial scale for the manufacture of fibre composites.
- infiltration of the resin between the layers. The fibres are aligned in a shape corresponding to the part and infiltrate (under vacuum or under inert gas pressure) the matrix material in liquid state.

Table 3. Experimental conditions.

Composite layer thickness, at 20°C [mm]	Hardener for 1 kg of resin [%]	Working time [min]
1 – 3	3	approx. 20
2 – 4	2	approx. 30
3 – 7	1	approx. 40

Flax, jute and hemp fibre–resin composite plates were fabricated with nominal geometries of 150 mm width and 150 mm length. As method to obtain the reinforced composite structures is used the simple lay-up process (Figure 6), using few 0/90° plain weave fabric layers (Figure 7).

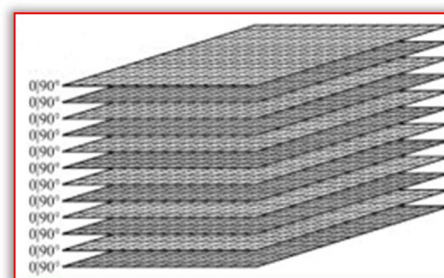
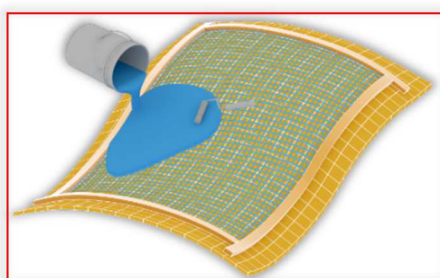


Figure 6. The simplified lay-up process. **Figure 7.** The 0/90° plain weave fabric layers.

The polyester resin used is an unsaturated, pre-accelerated one getting hardened at the ambient temperature. From the point of view of process-ability, the polyester resin is easier to use due to higher viscosity and low density. A hardener is added to the base component in a proportion that can vary between 1–3%, depending on the temperature and speed of the desired hardened. The hardener acts quickly and is highly concentrated, so a 2% addition is sufficient in most cases. The addition of hardener depends on the amount of base that is prepared at a single casting. The working temperature must be between 18–25°C, the higher the temperature, the harder the hardening. Practically, at a temperature of 0°C, hardening does not take place. Working time may vary between 20–40 minutes depending on the amount of the hardener added.

4. Conclusion

Bast fibres have many textile applications, with natural fibre composites being the fastest growing due to the combination of their relatively low cost and excellent technical characteristics. Jute is the second most common natural fibre (after cotton) cultivated in the world. Jute-based thermoplastic matrix composites find a substantial market in the automotive door-panel industry. Flax and hemp is amongst the natural fibres now finding use in thermoplastic matrix composite panels for internal structures (door and trunk liners) in the car industry.

Today, many automotive components are already produced in natural composites, mainly based on reinforced fibres (like flax or hemp). The adoption of natural fibre composites in this industry is led by motives of convenient price, weight reduction and ecological issues (like processing the renewable resources) rather than technical demands. For the natural fibres particularly these are often low cost, low abrasiveness (also giving potential health and safety benefits), good specific mechanical properties (on a weight basis, so very light designs are possible) and sometimes specific properties like good acoustic or vibrational damping and low coefficient of thermal expansion. Also, natural fibre composites in automobiles provide better thermal and acoustic insulation than fiberglass. Concerns about the environment, energy consumption and lightweight materials, place increasing demands for the use of sustainable materials in the top industries. As far as composite applications are concerned, flax and hemp are two fibres that have replaced glass in a number of components, especially in the automotive industries.

In spite of their benefits, the significant challenge for producers and supplier to handle with natural fibre reinforced polymer composites resides in large inconsistency of their properties. The chemical composition of vegetal fibres relies on several factors comprising fibre variety, time of harvesting, climatic history, soil characteristics and fibre processing technology. All these factors exert an influence on their final properties when used as reinforcements in bio composite materials. The variation within the mechanical properties of natural fibres is a challenge towards designing predictable components for industry since the engineers are accustomed to the precise and reproducible properties of synthetic fibres.

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