Recycling of textile wastes into textile composites based on natural fibres: the reinforcement type and the architecture

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Abstract. The textile composite materials market has witnessed an important growth in the past decades and is estimated to continue during the forecast period, according all statistics and trends. Since the last decades, the usages of various textiles composite materials in different applications have increased steadily, penetrating and conquering new markets, constantly. While textile composites are already proven to be weight–saving and high strength materials, the current challenge is to make these materials cost–effective by reducing the cost of different types of reinforcements (fibres, yarns or fabrics). The efforts to manufacture economically beneficial composite textiles have resulted in several innovative production techniques, currently being used in the area of the composites industry. Applications vary significantly in size and complexity, loading and surface quality, operating temperature, suitable production volumes and peculiar added value. The expanding choice of raw materials, in terms of the reinforcement type together with the matrix type, followed by many production techniques, gives impressive flexibility in manufacturing of textile reinforced composites. The aim of this work was investigation of the possibilities of reusing of textile wastes, especially the textiles derived from the packaging industry, as reinforcement in production of new added–valued composite materials.

1. Introduction
The increased ecological consciousness has generated the concept of the sustainable development of environmental material resources with improved economic activities.[1–7] Also, the waste legislation increased the pressure on solving the waste management through reuse or recycling processes.[1–7] In this sense, the recycling of textiles is an issue that requires immediate attention in order to address the management of textiles derived from various scraps generated throughout textile manufacturing processes, as well as household waste. One possibility for recycled fibres and different fabrics could be to employ them as reinforcement in the composites, which in turn could be used in several applications.[1–9] Natural based reinforced composite materials have enormous potential due to their light weight and ability to be manufactured in many complex shapes and structures. The steady increase in the use of composite materials has brought benefits in many areas.[6–10]

At the same time, the growing interest in research of natural based composite materials is mainly due to its low weight associated with moderate mechanical properties when are compared with the synthetic fibres.[8–13] Also, natural based materials (fibres or fabrics) are biodegradable, low in cost and relative easy to obtain. These properties are already being explored by some industries sectors,
like the automotive, which is already using natural based composites in car components and few structural devices.\[6–10\] In this sense, the bast fibres (like flax, hemp, kenaf, sisal and jute) are a promising reinforcements for use in natural reinforced composites on account of its low cost, low density, high specific strength, no health risk, easy availability, renewability and much lower energy requirement for processing.\[8, \[9, \[12–26\]

Therefore, environmental concern has resulted in a renewed interest in area of bio–based materials, among them, the bast fibres being perceived as an environmentally friendly substitute to the glass fibres for reinforcement.\[2, \[4, \[8–10, \[17–19\]

Several research projects have been carried out to develop the recycling methods and seek ways of effectively using recycled materials (including wastes) in new applications.\[1, \[4, \[12–14\]

Currently, the use of composites has had a great impact in the advanced industry areas, such as the automotive industry and construction and building materials.\[8, \[9, \[14, \[23\]

Mainly, those are related with the sustainability and the environment aspects.\[1–7\] Textile materials have been reused in the production of add–values products, crushed or cut, for manufacturing noise reduction and temperature insulation materials, and as reinforcements of natural based composites. \[6, \[8, \[9, \[15–26\]

The textile wastes are part of the solid wastes generated by the population and contains, mainly, used clothing or packaging materials.\[1–9, \[26\]
The textile recycling should be taken as a means to obtain few environmental or/and economic benefits for various reasons, as it contributes to the reduction of spaces required for landfills, reduces the need to produce virgin materials and reduces pollution.\[1–4, \[26\]
The use of recycled materials is primarily aimed at environmental preservation, but creation raw materials for the industrial area is a topical issue, with a promising industrial future.

In the past decades, special attention has been focused on the used clothes or packaging bags, which represent a source of raw materials environmentally responsible and economically profitable.\[3–6, \[16, \[22–26\]

Wastes from the production of textiles are undesirable but are inevitable by–products in many manufacturing processes, which are often not given the recognition and economic value that they actually have. Recycling textiles are an excellent opportunity to reduce the environmental impact of commonly used products.\[1–7, \[11–14, \[26\]

In this sense, the textile materials recycling involves:

— the re–use of used fibrous materials, mainly from the population, and
— the re–use of clothing manufacturing production losses.\[3–7, \[14, \[17–19, \[26\]

The textile recycling strategies are based on the knowledge of their classification;\[2, \[4–6, \[26\]

— post–production textiles (yarns or fabrics), which are losses of production process, and
— post–consumption textiles (clothing or carpets), which are discarded once its useful life expires.

Recycling from the textile waste stream includes the following activities:

— re–use of the textile waste in its original form, the largest volume of goods being sorted for second hand clothing markets, or
— conversion to new products, in which the fibre is then re–engineered into value–added products (car components or building materials such as insulation and roofing felt).\[8, \[18, \[22–26\]

The traditional textile’s recycling is based on introducing them back to a productive stream.\[20–22\] Upcycling is the process of converting wastes or useless products into a better quality’s or a higher environmental valued products.\[1–7\] The idea of using textile waste in applications that do not involve a new industrial process results in a novel recycling idea, due to the economic and environmental benefits that can be achieved.\[1, \[4, \[11–13, \[26\]

In fact, the existing materials are given more value, not less and the process is essential to minimize environmental impact and decrease the amount of waste that goes into landfills.\[1–7\] So finding possibilities to re–use the already created resources is a way to create an endless supply of materials without further depleting natural resources. Moreover, upcycling the textile waste is definitely a necessary step in closing the loop on textile manufacturing, getting the excess and waste under control and eliminate it whenever possible.\[13, \[22\]

2. About recycling of textile fibres and fabrics

The experts estimates that 95% of the textiles we use could probably be recycled, but only 25% actually are. Much of the remainder is incinerated or sent to landfill.\[1–7, \[10, \[15\]

Therefore, a solution is needed to recycle some of this end–of–life textile waste into a valuable resource, by
rethinking its use of resources for new materials like reinforcements in composites. It can be an alternative to a variety of existing materials depending on the application. In designing the new added-value materials, must be focused on making a composite that can replace or even bring additions to existing material offerings and thereby be an alternative.[4–7, 11–14, 26] Therefore, recycling of these solid textile waste may be viable alternative for industries. Textile wastes such as from fibre, textile and clothing can be sourced from the community, manufacturing industry and consumers. These are also known as pre–consumer, post–consumer and industrial textile waste. Meanwhile, the post–consumer textiles, often known as “dirty waste”, are collected mixed with other household items.[1–7, 11–14]

Material selection in the new added–values products is made during a complex and lengthy product development process. Actual selection of materials for a specific application is primarily driven by the trade–off between the cost of the material (including the purchase price and the processing costs) and its performance attributes (such as properties, quality and so on). In this sense, the use of textile fibres and fabrics, in specific applications, may solve several problems, namely:[8], [22], [26]
— reduction of spaces required for landfills,
— reduces pressure on virgin resources, using efficiently the resources, and
— promoting of an alternative material as reinforcing materials.

Recycling is a key concept of modern waste management, consisting in the reprocessing of waste materials into new or reusable products.[1–7, 11–14, 25], [26] The recycling of textile waste can helps to conserve resources and reduce the use of landfills, as we mention before. In fact, recycling has become a necessity, to protect the environment, sending textile wastes to the landfills being the last alternative in an integrated waste management system. But, in the light of a fierce need for raw materials, can be a solution to promote of an alternative material as reinforcing materials into natural based composites.

3. Comparison of properties: E–glass vs. bast fibres

Composite materials have at least two components in which properties are clearly different between them.[8–10], [14–26] Separately, these constituents maintain their characteristics, but when are mixed the combination of the two materials results in a “composite material”, which is superior in both form and function to that of the constituent materials separately.[8–10], [14–26] Therefore, the properties of the composites can be considered as a combination between the properties of the reinforcement and the matrix, in addition to the properties of interfaces between the reinforcement and matrix.

In general, in the polymer matrix composites, the fibres provide the strength of composite while the polymer, which is sometimes referred to as the matrix, provides dimensional stability and the transfer of shear stresses between the reinforcement. The role of the reinforcement is fundamentally one of increasing the mechanical properties of the matrix.[8–10], [14–26] The result is a strong functional material which can be used in a wide variety of applications.

Fibre reinforced polymer composites are composed of a polymeric medium such as polyester or epoxy, and a fibrous material — such as carbon fibre, glass fibre, aramid fibre or natural fibre. Natural fibre reinforced polymers have been identified as a potential low impact alternative to synthetic fibre reinforced polymers.[8–10], [14–26] Therefore, the replacement of glass fibre with natural textile for reinforcement in polymer composites appears to be a modern approach. Bast, leaf and fruit fibres have all been identified as potential replacement of glass in fibre reinforced polymer composites, bast fibres receiving the most attention,[16–26] Flax, jute and hemp have been identified as very important fibres for use as reinforcement in polymer composites due to their proven mechanical performance in comparison with glass fibre. For most other applications, the fibres need to be arranged into a fabric,
to make handling possible. Therefore, the reinforcement with natural textile fabrics (plain weaves, unidirectional fabrics and non–crimp fabrics) can be a solution. Subsequently, different types of textile fabrics were produced and evaluated as reinforcement in composites manufactured by well–established manufacturing techniques.[8–10]

Available material properties of natural textile used as reinforcements are reviewed here. In general, these materials are categorized into fibre, yarn and fabric forms. Bast fibres has been employed for centuries as a packaging material, but in recent times it is found to be a valuable aid to sound environmental management, bag cloth industry having the biggest consumer of these fibres available in the markets.[8–10], [14–25] Among all bast fibres, along with kenaf, hemp, flax and ramie, jute is one of the most significant and versatile fibres of commercial and technical importance, being one of the cheapest vegetable fibres and it is second only to cotton in the amount produced and the variety of its uses.[8–10], [19–24] Natural fibre bags have gained an advantage as being an eco–friendly option instead of both of non–biodegradable polymer bags and paper bags.

![Figure 2. Long fibres and fabrics: (a) flax; (b) hemp; (c) jute](image1)

![Figure 3. Fabric constructions: (a) 0/90 cross–ply layers; (b) 0/90 plain weave fabrics](image2)

In polymeric composite terms, a textile fabric is defined as a manufactured assembly of long fibres of carbon, aramid, glass or natural origin, or a combination of these – the term hybrid refers to a fabric that has more than one type of structural fibre in its construction –, to produce a flat sheet of one or more layers of fibres.[8–10] Woven fabrics are produced by the interlacing of fibres in a regular pattern or weave style. The large variety of possible textile preforms presents a challenge for natural composite materials science.[8–10]

Most fabric constructions offer more flexibility for layup of complex shapes than straight unidirectional tapes offer.[8], [9] The plain weave construction results from each fibre alternating over and then under each intersecting strand. Composites using textiles have drawn attention, since requirements and survivability are becoming increasingly important in different applications.[8], [9] Textile composites now in abundant production and their contribution has been landmarked by fibres used than fabric structure and fabric types.

### 4. Results & Discussions

Three different natural fibres were investigated in the present study (flax, jute and hemp) in comparison with E–glass. Density, modulus values, and specific modulus (modulus divided by the density of the material) and elongation to failure for the flax, jute and hemp fabric destined to fibre–resin composite fabrications were presented in Figure 4. Since compared with the bast fibres, glass
fibre do not absorb the moisture greatly, therefore, only the moisture content of the flax, jute and hemp fabric were presented in Figure 4.

Figure 4. Comparison of properties: E–glass vs. bast fibres (hemp, jute and flax)

The density of natural fibres is generally lower than that of E–glass: typically hemp fibre is 1.5 g/cm³, flax is 1.4 g/cm³, jute is 1.46 g/cm³, while glass can be as much as 2.55 g/cm³. Hence, the specific properties like specific modulus sometimes achieve a better ratio between E–Modulus and density than E–glass reinforced composites. The density of a material is a key consideration in application as a lower weight material can reduce costs in some areas of applications. While applications for natural fibre composites could be similar to glass fibre composites, several research has indicated that composites consisting of natural fibres have comparably low intrinsic mechanical properties compared with their synthetic fibre composites.

The application of natural based composites has increased and is gaining preference over glass fibre and carbon fibre, having in view that the natural based composites excel in most parameters except strength. Therefore, total global natural based composite materials market is expected to grow in the next years, the efforts must be carried out to find new uses for natural fibres or fabric resource wastes, including its utilization as reinforcement in polymer composites.

5. Concluding remarks

A significant amount of different wastes from the textile industry and post–consumer product are disposed worldwide. This is not only a cause for environmental concern but also represents a waste of useful resources. In fact, turning them into useful materials serves a dual function:
- elimination of textile wastes, and
- development of a new added–value product.

Last decades, natural based reinforced polymer composites have been investigated extensively. At the same time, the use of these composites has continuously increased during recent years due to their low cost and environmental friendliness. Natural fibres as a substitute for synthetic fibres such as glass fibre in composite components have gained renewed interest during recent years due to their properties, renewability, and also, their abundance. This has led to the application of various natural fibres, like bast fibres in many polymer reinforced composites in a wide range of applications, products made from textile–reinforced composites having the same advantages.

Considerable growth has been seen in the use of natural based reinforced composites in many industrial applications over the past decade, most developments being focused on the random discontinuous fibre composite systems. The development of continuous fibre reinforced composites is, however, essential for manufacturing materials. The current work aims to develop high–performance natural fibre composite systems using continuous textile reinforcements like woven fabrics. Textile fabrics are characterized by plaiting, good elasticity and fine porosity, can be processed slightly into fabrics, and they can retain suspended particles by absorption. The type, porosity and thickness of the fabric, further treatment give plies a wide variety and adaptability in finding new applications.
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