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Recycling of textile wastes into textile composites based on natural fibres: the valorisation potential

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Abstract. Natural fibre reinforced composites are gaining interest because of its attractive properties such as low weight, higher stiffness and low cost. Fibre reinforced composites are lightweight, strong, and durable materials which are seeing increasing adoption in the transportation, construction and many other markets. Therefore, sustainability in their use phase is often a key driver for the selection of composites over traditional materials. In the meantime, the ever–growing amount of textile wastes leads to the necessity to utilize these waste materials and to develop further processing technologies for their beneficial application. Due to various application possibilities and its economic impact, the valorisation of textile wastes has attracted increasing attention. This review summarized the valorisation potential of a textile waste products, especially of flax, hemp and jute fabrics. In this context application of different textile wastes for development of some value added product has been thought of in this paper.

1. Introduction

Textile waste is one type of municipal solid waste growing rapidly in recent years. Abundant textile waste which includes the waste generated from streams of fibre, textile and clothing manufacturing process, commercial service and consumption has raised increasing concerns worldwide in developing novel circular textiles approach. In fact, disposal of textile waste and their management have risen increasing global concerns in the recent years.[1–6]

In many cases, major recycling options for textile wastes include only second–hand oversea trading and energy recovery by incineration. Moreover, the short lifecycles of apparel product due to rapid fashion cycles and increased buying power of consumers in urban areas is resulting in significant amounts of postconsumer textile waste in the form of used clothing or even second–hand clothing. Post–consumer textile waste mainly originates from the household sources and consists of textiles which the owner no longer needs as it was.[1–4] Currently, for textiles which are ripped or stained and are no longer wearable, disposal commonly consists of landfill or incineration as there are no other valorisation routes available. This waste is often made up of resources, which could be recycled and used.[5–10]

In recent years the world has been involved with environmental issues related to the continuous use of natural resources, including the textile wastes.[9–14] Therefore, several proposed solutions involve the use of natural, renewable and recyclable materials. In this respect, the use of natural fibres and their wastes is a successful example being investigated and industrially applied since the past decade. [1–6], [15–24]. In particular, the lingo–cellulosic fibres obtained from plants are increasingly being considered as reinforcement of composites for engineering applications, especially in automobile components. Therefore, applications of natural–reinforced composites (with mixture of particle, fibre and textile structures) are expected to have a significant positive environmental impact.[5], [6], [15–24] The availability of the technologies for producing of natural–reinforced composites and its high socio–economic value are solid arguments in favour of the future development of this product and can find a wide application as a substitute for non–biodegradable or non–ecological products.[5], [6], [22–24]

Bast fibres (flax, hemp and jute), for their versatility, rightfully deserves to be branded as the "fibres for the future", being another natural option for a cleaner environment.[9–15] Among all the natural fibres, bast fibres such as jute, flax, hemp, sisal and ramie appears to be a promising fibres and constitutes large area of investigation due to its good mechanical properties compared with other natural fibres.[16–20] Recently, cellulose fibres began to be used as a fibre–reinforcement material, especially in conjunction with polymers in fibre–reinforced composites, due to their similar properties to engineered fibres.[18–20]

A huge amount of these fibres is wasted and is gone to landfill every year, either in the form of textiles resulted from manufacturing of fabrics or in the form of used cloths after the end–of–life of the bags. In fact, bast fibres and their wastes can be used not only in its traditional materials, but also for the production of other value–added products such as geotextiles or composites.[15–24] Concern for the environment, both in terms of limiting the use of finite resources and the need to manage waste disposal, has led to increasing pressure to recycle materials at the end of their useful life. As well known, the bags at the end of their longevity will be as waste materials. Moreover the waste fabrics are not yet reused effciently.[5], [6], [14], [15] Therefore, several attempts were carried out in our previous research [5], [6], [23] to use the above–mentioned valuable properties of bast fibres, to reuse the wasted textiles, to recycle the end–of–life fibre bags for fabricating valuable reinforced textile/polymer composites or textile sandwich composites.

Figure 1. Textile packaging material as solid wastes

The textile industry needs to find imaginative solutions to produce environmental improvements.[4–9] One of the main environmental concern in the textile industry is about the solid wastes, coming from the packaging of raw textile material of different nature (in form of fibres, yarns or fabrics) or paper packaging wastes (boxes, bags, cardboard), considered as non–dangerous wastes.[5], [6], [10], [11], [15]

Recycling the waste for environmental protection has been an important challenge for the mankind. The fibrous waste in textile industry accounts for approximately 15% of the amount of fibre products used.[7], [8] Nearly 95% of used clothing and textiles can be reused and recycled. Any clothing, household textile or commercial linen textile can be reused and recycled. Only items that are wet or have been used with a solvent–type liquid cannot be recycled.[7], [8] Nearly 100% of all used clothing and household textiles can be sort and grade the used clothing based on quality, condition, and type, re–used or recycled in one of the following manners:[7], [8]

— 45 percent is re–used as apparel that are then sold to the second–hand clothing industry or are exported to emerging market nations where demand for top quality second–hand clothing is particularly high.
— 30 percent of the recovered textiles are cut and converted into wiping rags or polishing cloths that are then used in commercial and industrial settings.
— 20 percent is reprocessed into its basic fiber content which are then remanufactured to create furniture stuffing, home insulation, automobile sound–proofing, building materials and various other new products.
— 5 percent is unusable. If the textiles are wet or dirty, broken or contaminated with solvents they are not fit for any recycling process and are finally discarded.

Therefore, more than 95% of all textiles can be recycled or reused in some way, only 5% is unusable due to mildew or other contamination.[7], [8] In general, applications of re–used or recycled textile waste belong to the following three broad categories: apparel, home furnishing, and industrial. Most of the fibre products are for short term (e.g. disposables) to medium term (e.g. apparel, carpet, automotive interior) use, lasting up to a few years in their service life.

The current study focused on the valorisation potential of use of packaging textile waste as reinforcement for producing a fibre–reinforced polymer composites. This paper discusses about the recycling possibilities of the textile wastes as reinforcements in the polymer composites and the applications of these in different areas. At current study, recycled bags was used to fabricate ecologically friendly composites.

2. Secondary textiles: from source to treatment

However, large textile type material lost in landfilling or incineration are unavoidable in the currently wasteful, linear system which creates negative impacts on the environment. It is important to find innovative solutions to valorise this waste to ensure that it does not add to the already significant environmental impact created by textiles.[1], [6], [9–13]

Ensuring that there are markets for the secondary textiles to be processed reduces the amount of textiles which end up deposited in landfill or simply incinerated, hence improving the “circularity” of these valuable items. As the quality of secondary textiles decreases, the options available become of less value, as highlighted in Figure 2. The strategy to textile waste management must give priority in the first place the waste prevention, in the second place recycling, reusing and revalorization of different textiles and finally their dump deposition.[10], [12]

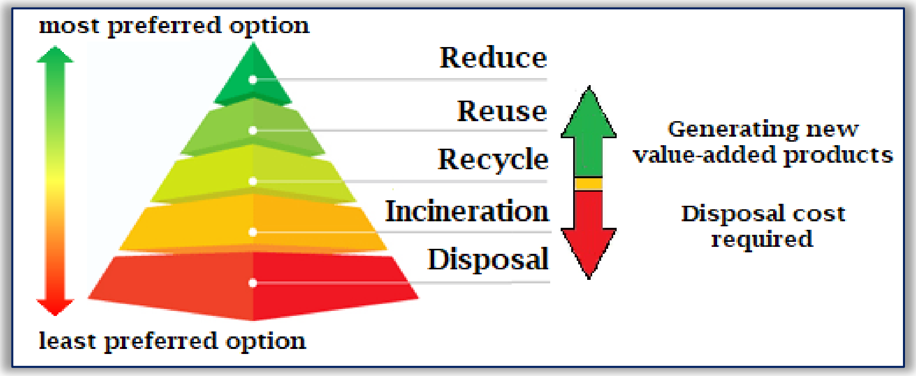


Figure 2. The textile waste hierarchy options

Different clothing and household textiles are a complex input materials for the textile wastes recycling process due to the variation in their composition, their quality at the point of disposal in landfills and the existence of alternative markets for textiles which have been recovered.[1], [3], [4], [11–14]

The available and most preferred options for waste textiles collected separately and sorted, considered as high–grade scope for material recycling, are highlighted in Figure 3. The least available options for waste textiles, separated or not at source, treated as municipal solid waste, considered as low–grade scope for material recycling which need disposal costs, are presented in Figure 4.

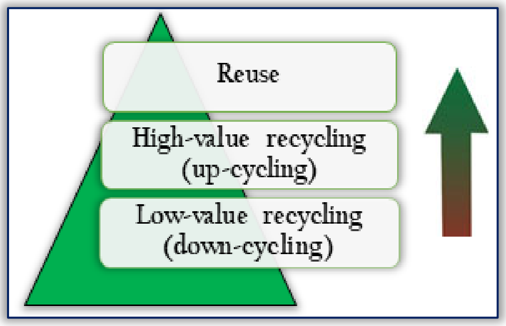


Figure 3. Flow diagram of waste textiles which can generate new value–added products

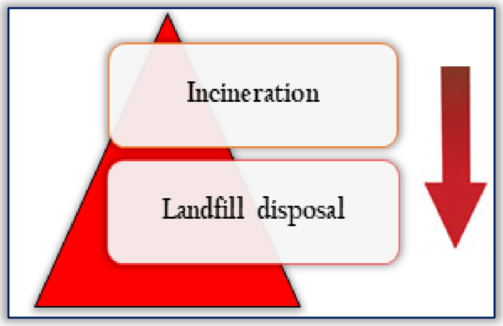


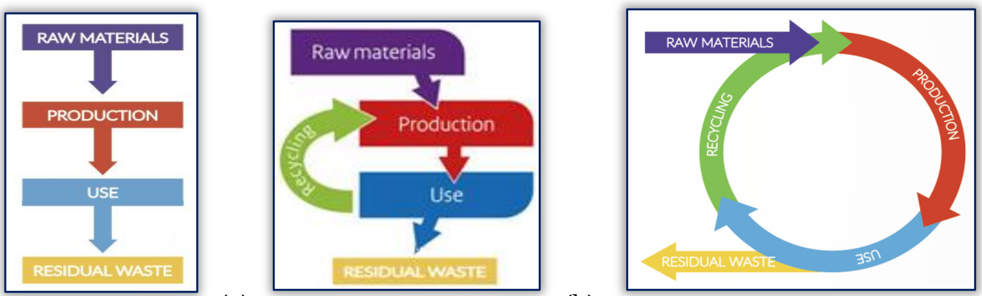
Figure 4. Flow diagram of waste textiles which disposal cost required

Also, the textile industry generates a large amount of waste and the textile manufacturing is worldly reported as the second most polluting sector and represents a complex, problematic waste stream. The growth of textile markets not only depends on population growth but also depends on economic and fashion cycles.[4], [9], [12–14] The fast fashion cycle in the textile industry has led to a high level of consumption and waste generation. This can cause a negative environmental impact since the textile manufacturing and clothing industry is one of the most polluting industries, being a chemical–intensive process. Wastewater and fibre or fabric wastes are the major wastes generated during the textile production process.[4], [10] On the other hand, the fibre and fabric waste was mainly created from unwanted clothes in the textile supply chain. This waste includes natural and synthetic fibre or fabric, and hybrid natural/synthetic blends.[6], [9], [12]

3. The recycling in practice

Concurrently, the valorisation of waste for useful materials production is a current practice, with particular focus on environmental indicators and sustainability goals and it is part of the larger endeavour of the circular economy (Figure 5). Outside of well–established reuse markets and mechanical recycling processes (where capacity limits exist), there remains a large quantity of low–value materials for which there is no market pull to utilize.

The move to a circular economy is becoming more widely discussed and adopted, largely thanks to its benefits. A circular economy approach to textiles involves moving away from our traditional “take, make and dispose” model and working to achieve a model whereby fibres or/and fabrics are kept in use and at their highest value. The ability to recycle used textiles – by use waste textiles to back into make new products – is of particular interest.



(a) (b) (c)

Figure 5. From linear to a circular economy (from waste to resource) (a) linear economy; b) reuse economy; (c) circular economy

Characterizing the linear economy, the economy with feedback loops, and the circular economy summarize the potential, and in some cases already proven, advantages of the circular economy approach in terms of three major categories.

— the production processes in this setup require significantly less newly produced or mined raw materials. Consequently, these processes become less sensitive to the growing need of many raw materials;
— the circular economy has the potential to generate innovations and new employment opportunities in the so called eco–industry, based on the development and application of eco–technology;
— the reduction of environmental damage due to less extraction of raw materials and significantly smaller waste disposal problems.

Products which have lost their functional value generally tend to form part of material left for recycling. Considering the impact of different measures, it appears that the greatest potential is to be found in the development of new technology. The challenge here is to develop value adding features. We all know what the basis of recycling is a practice that takes an item and targets it for reuse, returning it back to the cycle of daily contribution to society rather than discarding it to trash, meaning treat or process used or waste materials so as to make suitable for reuse, alter or adapt for new use without changing the essential form or use again in the original form or with minimal alteration.

Therefore, any recycling process is a first step in reaching a more sustainable solution of the waste management that can eventually limit the amount of new and virgin materials that need to be produced. In fact, recycling is undoubtedly useful, and is a conscious means for extending the useful lifetime of used materials. Therefore, any recycling process has simply prolonged the inevitable by stretching out waste stream and made the lifecycle costs of the material a bit less.

The circular economy has seen a significant increase in interest over the past few years, having several key elements as strategies, as follow:

— can prioritise the regenerative natural resources, and therefore the renewable and reusable resources are used as raw materials in an efficient way;
— can preserve and extend what is already manufactured, and, while resources are in–use, repair and upgrade or remanufactured them to maximise their lifetime and give them a second life through take back strategies when applicable;
— use the existent waste as a new resource, using waste streams as a source of secondary resources and trying to recover waste for reuse and recycling.

(a) (b) (c)

Figure 6. The recycling in practice: (a) recycling; (b) upcycling; (c) downcycling

In this way, materials destined for landfills or incineration can be recycled in scope to produce something completely different. The process where waste products are converted into a new materials of better quality and a higher environmental value is the upcycling i.e. remaking of textile material wastes to something new of greater value, like reinforcements in a composite materials. Upcycling involve creative ways of reuse old materials by using different pre–consumer or post–consumer waste or a combination of the two. In fact, the upcycling becomes dually important:

— first, the practice reduces the amount of waste that we produce and ultimately goes into the ground for longer than any of us will be around.

— secondly, it also reduces the need for virgin material to be harvested as feedstock for new generations of product.

Upcycling represents a truly cyclical, balanced process that all industries and companies should be aiming towards. All of products could be drastically changed if the beginning of their design started with the goal of not having them end up in a landfill, as is been thinking in the circular economy. A number of ways could be utilities to train the economy into an inherent practice of reuse. Upcycling is a process that can be repeated in perpetuity of returning materials back to a pliable, usable form without degradation to their latent value–moving resources back up the supply chain.

Upcycling is described by some as reusing a material without degrading the quality and composition of the material for its next use. As a result, these usually become products that will eventually also become trash. In fact, upcycling is equivalent in material terms to the "reuse" step in the classic waste hierarchy (reduce–reuse–recycle), though rather than being direct reuse of the same product, its reuse of the materials in an equally useful way. Therefore, upcycling is a process where waste or useless products are converted into new materials or products of equal or better quality or a higher environmental value. Moreover, by making use of already existing materials the consumption of new raw materials for new products is reduced. Hence, upcycling is an even greener way of recycling, better environmentally and cost efficiently.

4. Innovative recycling technologies for textiles – A potential solution

A potential solution is the development of innovative recycling technologies for textile materials. In this sense, technical textiles are a field envisaged by the European strategy, and consist of textile materials with technical applications, in fields like industry or agriculture. To improve and reach a significant valorisation, integrated processes for proper separation, detection and classification of textile waste from industrial and commercial packaging waste are promoted. In this sense, several research and industrial approach suggest the proposed technical solution, as a strategy for textile waste recovery from the disposal in landfills, with a great potential in treating textile waste and facilitating the recovery of natural textile wastes as value–added products into natural fibre reinforced composites.[6], [9], [15–24]

Textile wastes has gained a tremendous interest during the ten last years and will be a subject for significant research progress in the future, working on a recycling technology to enable low–value blended textiles to be collected, separated and processed into new raw materials as reinforcement into composites. The emerging applications of these materials (fibre and textile recycling, focusing on the case of natural and synthetic textile fabrics, which account for a large part of textile waste) as reinforcements in the manufacturing of natural fibre reinforced composites is one of the valorisation approach. The natural fibre is mostly comprised of cellulosic material, which can be used as a resource for producing fibre–based products like composites. The main challenge for utilization of various textile waste is finding the method that is able to recover it as reinforcements in composites. Another interesting contribution is proposed on geo–polymers used in agriculture. This category of new high–added value textile products comprises the properties of textile materials (light–weightiness, flexibility, resistance) and offers adequate solutions for the specific technical purpose.

Therefore, developing markets for the lowest grade textiles can have wider benefits, including supporting the manufacturing of natural fibre reinforced composites. Moreover, technologies of composite materials could be a feasible solution for the textile waste valorisation and the textile wastes consisting of natural and synthetic textile fibres or fabrics in various ratios can be used as low–cost raw materials in high–added value products.

In recent years, there have been collaborations between brands and innovator companies, with the overall aim of developing recycling technologies which deal with the textile waste problem. With the increase in clothing consumption, greater amounts of textiles are being discarded, some of which having hardly been worn. Knowledge of the markets considered as inputs (textiles wastes) and outputs (natural fibre reinforced composites) for the recycling process has been quantified to identify the overall opportunity, alongside technology development.

5. Concluding remarks

Due to environment and sustainability issues, this century has witnessed remarkable achievements in the composite technologies through the development of natural fibre composites. The development of high–performance materials made from natural resources is increasing worldwide. The greatest challenge in working with natural fibre reinforced polymer composites is their large variation in properties and characteristics. However, with appropriate attention to fibre and resin design and structural geometry, natural fibre composites may prove a viable alternative to traditional materials in the future. Industrial ecology, eco–efficiency, and green chemistry are guiding the development of the next generation of materials, products, and processes.

The current interest for natural fibres from textile wastes as an environmentally correct composite reinforcement has motivated the investigation of new possibilities. For instance, the textile fibres from the textile wastes were recently found to have adequate mechanical properties to reinforce polymer composites. Most natural fibre composites, including the textile waste inserted composites, however, are fabricated with traditional non–degradable polymer matrix but still presenting a recycling advantage over the common glass fibre reinforced polymer composites. Therefore, textile waste inserted composites stand out as a relevant class of engineering materials.

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