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TEXTILE WASTE: A NEW OPPORTUNITY

by, Dr. Farshid Pahlevani

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Fig. 1

Textile Waste: A New Opportunity

by, Dr. Farshid Pahlevani,

Abstract

The Textile Industry is the second most polluting sector in the world, accounting for the 10% of the total world's carbon emissions. Contributes to a complex, profuse, and fast generating post-consumer waste stream of unprecedented rate; estimated of 92 million tonnes in 2015. The relevance and key advantage of this end-of-life waste stream relies in the latent potential of a material blend rich in complex polymers and bio-polymers, which the traditional waste management protocol of incineration or landfill disposal has become obsolete, due to its major detrimental environmental consequences. This article aims to show how we can recover these assorted end-of-life textiles with the emphasis on promoting multi-stage cascading use of mixed fibre bulk, as a low-carbon alternative feedstock, for the advancement of Textile Fibre Reinforced Composite (TFRC) materials, for building applications.

I. *ENVIRONMENTAL IMPACT OF WASTE TEXTILES*

The population growth has increased exponentially at a global scale in the past decades, driven by migratory displacements, product of social changes, as well as by diverse political and economic scenarios. This trend is expected to continue to grow in the following decades, from a current world population of 7.6 billion to approximately 9.8 billion by 2050 (United Nations, 2017), concentrating 70% of population in large urban settlements. As consequence resources are undeniably becoming exponentially limited and climate change is a certainty with unprecedented characteristics; expected to cause severe consequences, at all levels (Wu et al., 2016). Unusual local weather conditions, fresh water and agricultural land scarcity with critical biodiversity loss, are some of the major challenges.

Fig. 2

Fig. 3

In this scenario, textile fibers are commodity products part of the fundamental goods that society will continue to require, in large quantities for several applications. The current textile manufacturing industry involves a primary extractive practice, which greatly depends on the availability of natural resources, which are at a critical stage of availability. It has been reported that 'textile manufacturing contributes for the 10% of the world's carbon emissions, the second most polluting sector in the world and represents a complex, challenging waste stream' (Bell et al., 2018). For example, the production of the most common soft commodity crops of lingo-cellulose based fibres, such as cotton, is product of an intensive water consuming industrial agricultural practice, which depends on Genetically Modified GMOs seeds, extensive monoculture areas, with unavoidable consequences of soil degradation, as well as bio-diversity loss (Aydin et al., 2013; Herring, 2015). For a 1.0kg of cotton about 7,000 to 29,000 litres of water and approximately 0.2-1.1 kg of oil are required (Kadnikova et al., 2017; Muthu et al., 2012b; Yun et al., 2017). Similarly, protein based fibres, such as wool (α-keratin bio-polymer) requires livestock stewardship in which intensive grazing, land erosion, and methane greenhouse gases have been reported as the major consequences (Harle et al., 2007; Wiedemann et al., 2016).

Furthermore, 70% of the world's textile consumption corresponds to synthetic fibres, such as nylon, acrylic, polyester, and polypropylene, which are polymers derived from petroleum extraction. Therefore, the textile industry is a high-embodied energy and natural resource demanding practice that generates a substantial environmental footprint, at each stage of the supply-chain. From the cultivation and synthesis of the fibres, to the yarn and fabric manufacturing, to the landfill disposal of post-consumer items at the end-of-life cycle (Muthu et al., 2012a; Rochman et al., 2015).

Fig. 4

In this context, the quantification of the environmental impact caused by the global virgin fibre production (GFP) production (Corporation, 2018), the environmental impact of the global apparel consumption (GAC) through landfill disposal, and the environmental advantage of recycling versus incineration, has confirmed it is of global relevance to extend the service life these materials (Muthu et al., 2012b). Researchers have specified the textiles, as decompose in landfill; contribute to the formation of both leachate and greenhouse gases (GHG), such as methane gas. The cellulose-based synthetics decay at a faster rate than chemical-based synthetics, which prolong the adverse effects of both, leachate and gas production. Furthermore, the decay of wool fibres produce large amounts of ammonia gas, which is highly toxic, both in terrestrial and aquatic environments, as 'it has the potential to increase nitrogen in drinking water, which can have adverse effect on humans' (Gadkar and Burji, 2015).

Fig. 5

On the other hand, incineration chimneys for thermal or electrical energy recovery 'emit organic substances such as dioxins, heavy metals, acidic gases and dust particles, which are all potentially harmful to both humans and the environment' (Gadkar and Burji, 2015). From the conservation of energy perspective researchers have reported the advantage of textiles recycling is considerably higher versus the energy generated by incineration, estimated for the most relevant fibres the total conserved energy kWh per ton is: 3531 vs 611 for cotton; 4889 vs 611 for nylon and acrylic; 7203 vs 1761 for polyester; and 16,389 for wool.

Similarly, the total ecological footprint of virgin material production (EFV) vs the ecological footprint of land-filling (EFL) significantly differ, where only the wool fibres disposal has minor impact in comparison to virgin material production (Table 1). Regarding the CO_2 equivalent emissions per kg of fibre (CO_2 eq) the virgin material production vs the landfilling is: 0.4 vs 700 for cotton; 8 vs 89.7 for nylon; 2.8 vs 700 for polyester; and 86 vs 700 for wool, also confirming recovering the waste fibres contributes to lower the total carbon emissions.

From the total energy (E) and water (W) requirements per kg of fibre manufacturing, major energy conservation can also be achieved by bulk fibre recovery of textiles vs virgin material production, with an estimation of 493 MJ/kg and 29,890 L/kg, respectively.

Staple fibre	Resources	Primary industry	Polymer	GFP %	GAC %	EFV Pt	EFL mPt	E MJ/kg	W L/kg	VP-LF Kg CO2 eq
Cotton	Plant seed	Agriculture	α-cellulose	33	27	0.001	77.5	55	7,000-29,000	0.4-700
Wool	Animal staple	Ovine livestock	α ,β-keratin	1.5	1.3	604	77.5	63	130-165	86-700
Polyester	Petroleum	Crude oil extraction	Polyethylene terephthalate (PET)	51.5	55	7.9	77.5	125	62	2.8-700
Nylon	Petroleum	Crude oil extraction	Polyamide	5	4.7	16.2-20.2	89.7	250	185-663	89.7

TABLE 1

Nonetheless, the textiles disposal fast rate is not arbitrary. 'These articles are discarded either because they are worn out, damaged, outgrown, or have gone out of fashion' (Gadkar and Burji, 2015). It has been confirmed a correlation between the escalation of clothes consumption with the volume of total waste generated (Caulfield, 2009; Madsen et al., 2007; Morgan and Birtwistle, 2009; Morley et al., 2009). The apparel market –the largest global consumer of textile fibres– (Textile exchange, 2016) promotes a fast consumption pattern of miscellaneous wearables, all of which are deliberately designed with an inherent built-in obsolescence. Specifically, in the clothing sector a fast fashion culture thrives on the regular replacement of items, which availability and affordability results in large volumes of textile-based materials (Boone, 2009). This phenomenon leaves a volume of global fashion waste accounted for 92 million tonnes in 2015 and estimated to increase to 148 million tonnes in 2030 (Truscott et al., 2017), a volume comparable to other major fast growing waste streams, such as e-waste.

In addition, the textile recycling industry still is in its early stages, generating a surplus of valuable polymer items, highly underutilized. For example, in the European Union (EU) about 5.8 million tonnes of textile wastes are produced each year; nonetheless, only a quarter of the total bulk is recycled into low-value products, or reduced by incineration. The remaining 75 % is destined to be disposed-off in landfills (Briga-Sá et al., 2013). However, the total waste bulk increases taking into consideration similar trends of highly-demanded textile-based waste streams (Figure 1) contributing also to large volumes of waste generation, such as upholstery, mattresses, bedding, packaging, rugs and carpets, and automotive interiors, (EPA NSW, 2015).

As discussed these post-consumer polymer fibres constitute a highly valuable resource that critically requires an integrated model based on Industrial Ecology (IE), targeting the cascading use of these raw materials through a cleaner production scope. Extending these materials service life requires a long-term multi-sector engagement which coordinated processes and logistics guarantee a reliable volume and consistent supply of raw material at low-cost (Wang, 2010); diversifying the commercial operations to produce a variety of high-end products, similarly optimized from the design phase, as an input material for future applications.

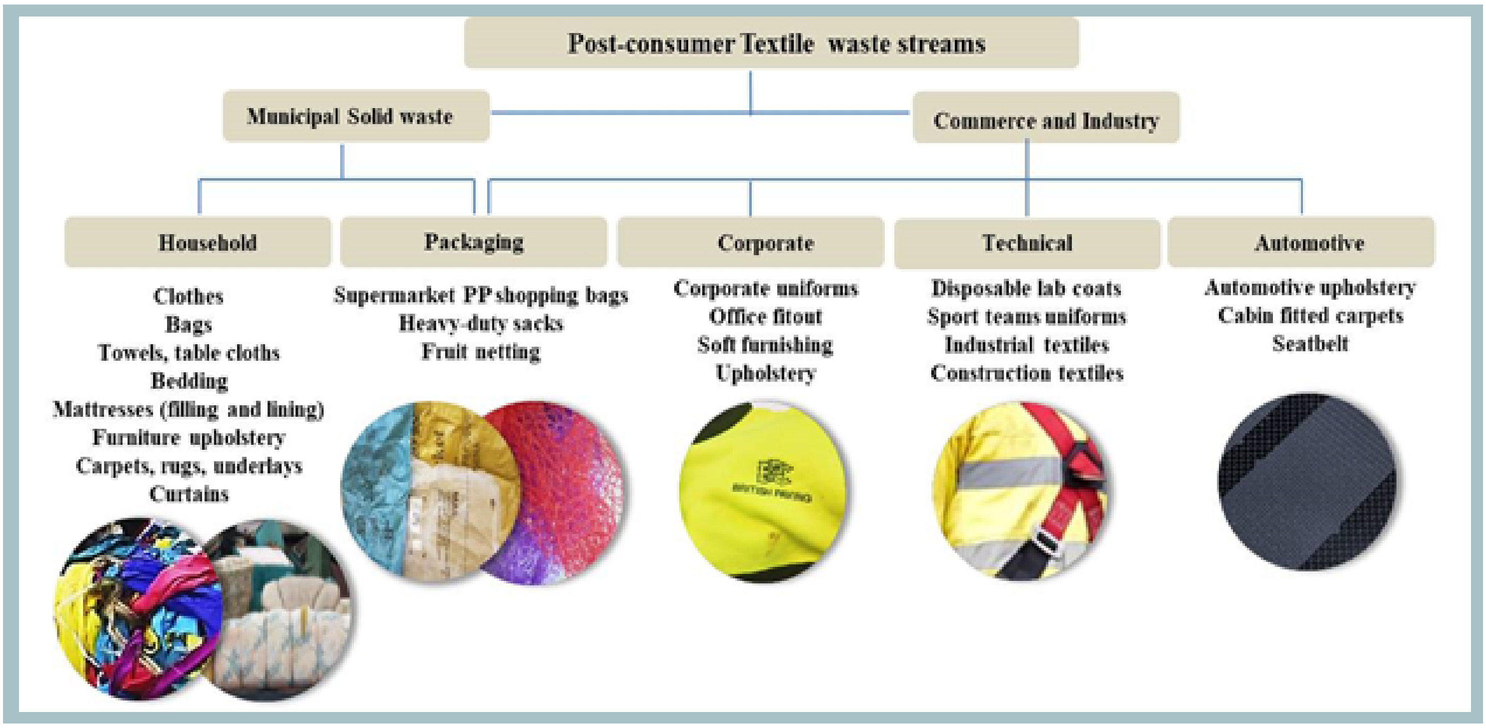

Fig. 6

II WASTE TEXTILES RECOVERY ROUTES

In the local context, the Government of Australia through the New South Wales Environment Protection Authority (NSW EPA) launched in November 2016 the ‘Circular Threads Initiative’ incorporating the IE model to the textiles waste streams; designating economic resources for a multi-sector engagement, targeting the cascading use of valuable textiles materials to be systematically directed back to industry, potentially diverting the 150,000 tons of end-of-life textiles that are currently disposed in NSW landfills every year (Australian Broadcasting Corporation, 2016).Nonetheless, the recovery of textile wastes as feedstock for new applications is currently limited by a distinctive gap between the current recycling technology and the cost-effectiveness of manufacturing these new products, at commercial scale. This is due to factors such as the material recycling times and the overall chemical burden. Plastic fibres shorten and degrade each time they are recycled, with a limit estimated of 7-9 times, and Cellulose fibres 4-6 times, before they are no longer suitable for recycling. Other major concern is that “over 8,000 chemicals are used in textile processing, some so hazardous that OSHA requires textile scraps be handled as hazardous waste. The final product is, by weight, about 23% synthetic chemicals” (Oecotextiles, 2016).

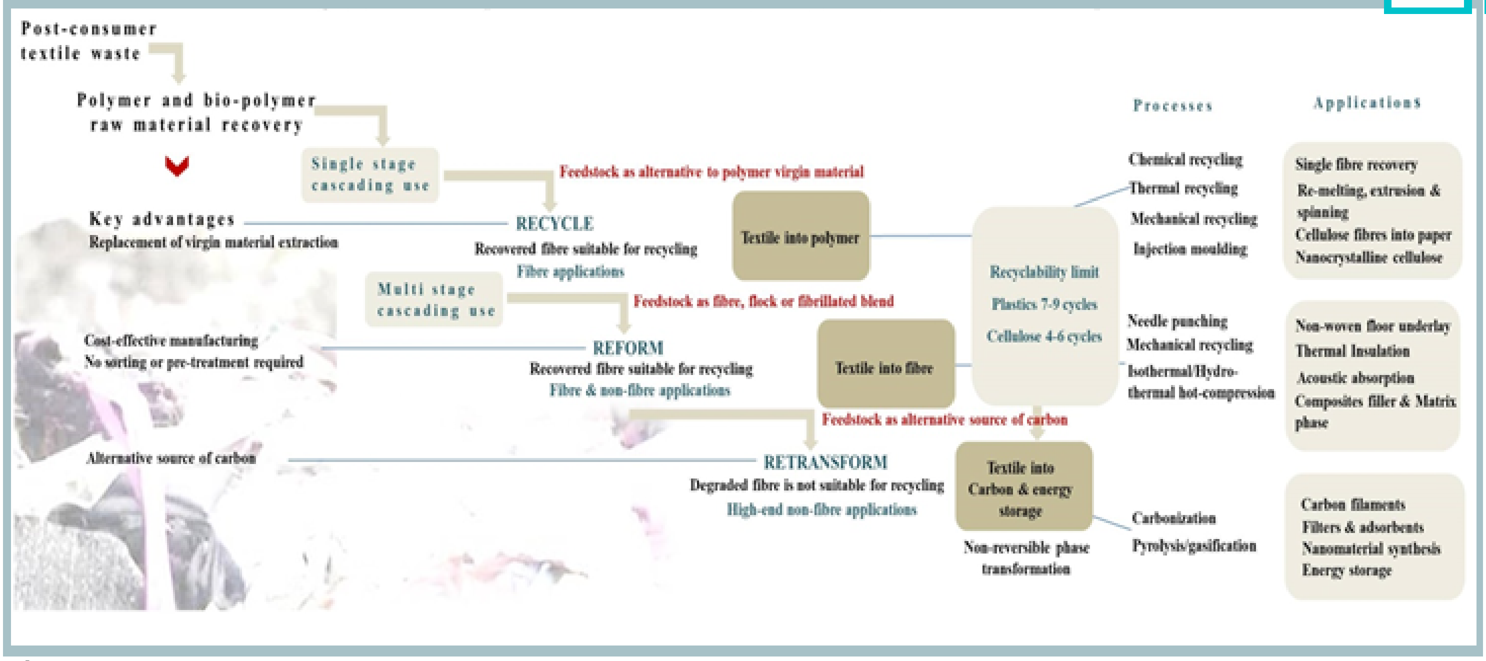

Fig. 7

These chemicals –dyes, mordant, softeners, flame-retardants and preserving agents– significantly restricts the fibres recovery at the end-of-life; since introduces further costs, not only by the sorting phase (Ekström and Salomonson, 2014; Khan and Islam, 2015; Palamutcu, 2010), but also by the limit levels of hazardous chemical and heavy metals content, acceptable in the recovered fibre bulk, as some of these are classified as mutagens, carcinogens, and endocrine disruptors (KEMI, 2014).
To address these major challenges, a great effort has been made. Several studies (Aronsson and Henriksson, 2017; Palme et al., 2017; Peterson, 2015; Sheikh et al., 2015; Shojaei et al., 2012) have reported advancement in singular material recovery, such as cellulose extraction from textile-based materials for textile applications, were the most researched fibre material is cotton 76% (Sandin and Peters, 2018). However, a ‘textile into polymer fibre’ single-stage cascading approach might not necessarily imply a cost effective solution. Instead, a ‘textile into fibres’ multi-stage cascading approach diversifies the outcome with a greater long-term economic prospective; by minimizing the sorting and pre-treatment phases, and targeting the direct transfer of mixtures into potential high-end products, such as building applications.

III RECYCLED TEXTILE POLYMERS FOR BUILDING APPLICATIONS

The focus of this study is to transfer textiles fibres into fibre reinforced composites for building applications. In the literature, several authors have investigated this potential for individual fibres as reinforcement in polymer, as well as cement composite materials (Araújo et al., 2017; Broda and Brachaczek, 2015; Miao et al., 2000; Pickering et al., 2016; Tasdemir et al., 2010). However, the relevance of this research relies in the study and characterization of the assorted textile ‘complex mixture’ as a filler phase, and a

Fig. 8

polypropylene textile waste as the matrix phase, into novel Textile Fibre Reinforced Composite (TFRC) sheet panels, which to the best of our knowledge is unprecedented until date. Within a low-carbon cost-effective multi-stage cascading scope these experimental prototypes must achieve low-embodied energy, non-toxicity, as well as suitable for further recycling at the end-of-life.From the materials perspective, the recovery of these polymer textile wastes present advantages in comparison to other waste polymer streams. This is because the arrangement in which the polymer chains link together within a staple fibre, display unique characteristics in comparison to other brittle plastics, as well as the elastomer items. However, the major challenge with this complex mixture is to achieve a high-level of filler-matrix interfacial compatibility, with minimum cross-contamination due to components, such as zip fasteners, laces, belts and buttons, inherent to the apparel waste stream.

Fig. 9

Regarding the reinforcement potential of the four major waste fibres as composite filler phase, materials properties such as mechanical strength, moisture resistance, and thermal performance are directly related to the individual characteristics of the polymers molecular structure (NPTEL, 2014). In polymer fibres two phases are identified: the crystal structure, which contributes to the strength, and the amorphous region, which is responsible for the elastic-plastic, as well as the hygroscopic behaviour.

ABOUT THE WRITER

Dr. Farshid Pahlevani is an internationally award-winning scientist and engineer who was selected as Australian's most innovative engineer in 2020. Farshid's work focuses on the sustainability of materials and processes with an emphasis on environmental and community benefits. He works collaboratively with companies and institutions in Australia and around the world and has established strong partnerships and a deep knowledge of industrial processes and problems.He has extensive experience of working with manufacturing industry.

Dr. Farshid Pahlevani
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His unique approach in creating innovative solutions is to generate, test and validate these solutions while also considering them against the business models and technical capabilities of industry to maximise their benefit and uptake.

He has six international patents and his technologies have been implemented in Japan, Singapore, Thailand, South Korea and Australia. Just in the last four years, he has successfully delivered over $6 million of research programs in Australia in direct collaboration with manufacturing industries. Companies that implemented and commercialise these technologies internationally achieved great economic benefit and environmental impact while diverting millions of tonnes of wastes from landfill.