

Recycling, Renewing and Reusing of Textile Waste and Resource: A Mini Review

¹MD Zahidul Islam

²Prof.Dr. Nihat ÇELİK

¹Assistant Professor, Department of Yarn Engineering, Bangladesh University of Textiles, Bangladesh.
²Professor, Department of Textile Engineering, Faculty of Engineering, Cukurova University, Adana, Turkey.

ABSTRACT: Textile production is the fastest growing sector in the world. With the increased population in the world, clothing demand is increasing day by day. Textile production is facing to gradual pressure to meet up that increased demand. Cultivation of natural fiber, synthetic fiber production, from fiber to yarn stage, weaving, knitting, dyeing to garments production are the vital source of carbon di oxide gas emission, creating a negative impact on the environment. Disposal of waste clothing as a landfill, creating a huge negative pressure on the environment. Recycling and reusing of textile product can reduce the use of virgin fibers as well as reducing the negative impact on the environment. Textile production from renewable resource creates less amount of green-house gas emission, reducing the usage of non-renewable resource, ultimately generating a positive effect on the environment. In this work, a brief review was made on the basis of a number of published paper addressing recycling, renewing, and reusing of textile resource and waste and their effect on the environment. It was investigated on this review work that, with the tremendous fashion change and rapidly growing population recycling, renewing and reusing of textile waste and resource has proved itself a urgent issue as it reducing the stress of the production of virgin fiber as well as reducing the emission of carbon di oxide being a positive effect on the environment.

KEYWORDS: Nonwoven insulation, Tire textiles, Regenerated cellulosic fiber, Vegetable oil, Fibre reinforcement.

Date of Submission: 25-04-2019

Date of acceptance: 05-05-2019

I. INTRODUCTION

Textile reuse refers to various means for prolonging the practical service life of textile products by transferring them to new owners, with or without prior modification (e.g. mending). This can for example be done through renting, trading, swapping, borrowing and inheriting, facilitated by, for example, second hand shops, flea markets, garage sales, online marketplaces, charities and clothing libraries. In the academic literature, various forms of reuse have been conceptualized in terms such as collaborative consumption, product-service systems, commercial sharing systems and access-based consumption. **Textile recycling**, on the other hand, most often refers to the reprocessing of pre or post-consumer textile waste for use in new textile or non-textile products.[1]

The increasing interest of the use of natural products due to problem in the environment, in the Waste disposal and depleting the renewable resource. The renewable resources is offering a better platform to substitute partially, and to some extent totally, petroleum based polymer through the design of biodegradable polymer which can compete or even surpass the existing petroleum-based polymer with lower value and positive environmental effect.[2]

Reuse is the first process of recovering waste and a crucial strategy in the so called, Today the main goal of the European Union is to close the loop of product life cycle with the circular economy. Textile materials are discarded as the waste, when they are perceived as being damaged or gone out of fashion. A lot of reusable item contained in the waste which could have extended life time in their repurposed form. Many charitable organization and private company collects these reusable item and resell them as second hand Textiles.[3]

Though textile sector play a great role in the negative impact of the environment, textile waste has only within the recent years started being governed as a part of the waste area. Probably, textile sector add smaller waste fraction, the potential contribution to climate change is very high per weight unit. That means there is a potential chance to improve the environment. This only can be realized by ensuring that textiles are collected, reused, recycled and disposed of in the best possible way. Knowledge about the disposed textiles is very much crucial in order to assess whether textile material can be reused, recycled or actually treated as waste.[4]

Synthetic fibers imposed more environmental impact because they deplete fossil feedstock than products made from renewable resource. Global warming potential (GWP) 100 years of polyester fibers is 4.1 t CO₂ equivalent/t fiber, while GWP of cotton fibers is 2 t CO₂ equivalent/ t fiber and 0.05 t CO₂ equivalent/t fiber for lyocell fibers in the cradle –to-factory gate. Moreover it is important to design a product in terms of environmental approach. To make a product from renewable resource and environmental friendly fibers is one of the important stage. Use of more eco-friendly production process is another important stage. The use phase parameter can be regulated in such a way so that it can impose less environmental harmful impact. Biodegradability of the materials is also another important function with regard to harmful impact on environment and people's health. There is a significant different exist between bio-polymers and petroleum based polymers in the correlation between green design and lifecycle environmental impacts. Biodegradable polymers is top of the green design classification because of their low energy demand, use of renewable materials, and biodegradability. New generation ecofriendly fibers such as polylactic acid, lyocell and chitosan fibers has been significant role in textile industry recent years.[5]

II. LITERATURE REVIEW

In the European Union (EU), around 5.8 million tons of textiles are discarded by the consumers per year. Only 1.5 million tons (25%) of these textiles are recycled by charities and industrial enterprises. The remaining 4.3 million tons goes to landfill or to municipal waste incinerators. Adding to this type of waste, there is also the textile waste from the textile industry. This shows that there is a enormous source of secondary raw material that is not used, but can be re-injected into the market. Thus, environmental concerns with the waste resulting from the textile industry have been increasing. This issue has been addressed by the European policies in order to define laws to regulate the management of waste. In order to encourage recycling in the EU, the Directive 2008/ 98/EC has been published on December 2008, as a recast of the Waste Framework Directive (WFD), Directive 2006/12/EC.[6]

The apparel industry is of great importance to the economies of every country in terms of trade, employment, investment and revenue. In 2015, the size of the global apparel market reached USD 1685 billion. At the same time, supply chain processes are characterized by fragmented and relatively low-tech systems, which have major environmental impacts such as the use of large quantities of water and chemicals, high emissions of greenhouse gases and generation of waste. A recent attempt to assess the global impact of the textile sector is by the Ellen MacArthur Foundation (2017) in “Appendix B.2: Resource use and negative externalities associated with material flows”. Global annual figures are given for: Total Greenhouse Gas Emissions (GHG) (1200 million tons); water usage (93 billion cubic meters); fertilizers for cotton (8 million tons); pesticides for cotton (200,000 tones); chemicals (42 million tons) and dyestuffs (1 million tons). For comparison purposes, the greenhouse gas emissions for cotton production are estimated as 4.7 kg CO₂e/kg fibre; for plastic-based fibres production are estimated as 11.9 kg CO₂e/kg fibre; for yarn and fabric production, including dyeing, are estimated as 9.6 kg CO₂e/kg fibre. Regarding water usage requirements: the figure for cotton production is estimated as 4600 L/ kg fibre; for plastic-based fibre production is estimated as 38 L/kg fibre; and for dyeing textile materials is 88 L/kg fibre. The share of textiles in total municipal solid waste generation in 2014 in USA accounted for over six percent (16.22 million tons), out of which 16.2 percent (2.62 million tons) was recycled, and 64.5 percent was landfilled. The EU textile industry generates waste estimated at 16 million tons per year. Much of this waste is incinerated. According to the Ministry of Environment of Korea between 2008 and 2010, textile waste volume increased by 17 percent, from 54,677 to 64,075 tons, respectively. The reuse and recycling of textiles could be considered as a route to socio- economic benefits and a means of boosting a nation's economy. Indeed, the advocacy for a “circular economy”, in which materials continue to circulate in the economic system in a cascade of reuse and recycling, has been gaining strength as it is translated into commitments made by policy, business and civil society representatives. In a report commissioned by the European Union, consultancy firm McKinsey estimates that the transition to a circular system could generate a net economic benefit of €1.8 trillion by 2030. More recently, reports by the Club of Rome have concluded that the circular economy would deliver socio- economic benefits in the form of enhanced energy efficiency, reduced carbon emissions and the creation of employment in the EU. For the textiles sector specifically, an economic system in which fabric and fibre recycling is fully integrated, has been said to reduce resource needs (water, fossil fuels, chemicals) and to generate new jobs in the collection, sorting and recycling of clothing. These socio-economic benefits have been widely projected, yet the available evidence remains scarce.

Every phase of the life cycle of textile waste recycling creates employment and gives opportunities for small or family businesses. More often, textile recycling is considered not as an end in itself, but as a route to implement the circular economy, i.e. a closed loop production system. It could become one of the solutions that helps companies in the process of moving towards sustainable business performance. Textile recycling leads product manufacturing towards a reduction of production costs, depending on recyclable materials being a low-cost and efficient alternative with low environmental impact. As an example, ECOSIGN (2017) reported that recycling secondhand clothes could reduce greenhouse gas emissions by 53%, reduce pollution associated with chemical processing by 45%, and reduce water eutrophication levels by 95%. The recycled materials could be applied in many fields such as automotive, furnishing, sailing and/or insulation, e.g. for production of geo-fleece, carpet underlay, rear shelves in car, stuffed toys, shoe insoles, etc. Part of the waste produced in the areas of spinning and weaving can be forwarded to recycling units, where they are subjected to a process of fibre recovery. Recycled fibres then become a constituent part of the pool of resources of the textile/clothing industry similar to natural fibres such as cotton or linen, allowing the generation of additional value.[7]

III. CLASSIFICATION OF TEXTILE WASTE RECYCLING

Textile waste routes are typically classified as being either mechanical, chemical or, less frequently, thermal. This is in many cases a simplification of reality, as recycling routes often consist of a mix of mechanical, chemical and thermal processes. For example, chemical recycling most often refers to a recycling route in which the polymers are de-polymerized (in the case of synthetic polymer fibres derived from petrochemicals, such as polyester) or dissolved (in the case of natural or synthetic cellulosic fibres, such as cotton and viscose). Having thus been disassembled to molecular levels, monomers or oligomers are re-polymerized, and polymers re-spun into new fibres. However, prior to the de-polymerization or dissolution, the recycled material is most often mechanically pretreated. Moreover, thermal recycling often refers to the conversion of PET flakes, pellets or chips into fibres by melt extrusion, but the flakes, pellets and chips have been produced from PET waste by mechanical means, which is why this recycling route is sometimes referred to as mechanical recycling. If the fabric of a product is recovered and reused in new products, we refer to this as fabric recycling. If the fabric is disassembled, but the original fibres are preserved, this is fibre recycling. If the fibres are disassembled, but the polymers or oligomers are preserved, this is polymer/oligomer recycling. And if the polymers/oligomers are disassembled, but the monomers are preserved, this is monomer recycling. Then there are various means of achieving these types of recycling routes, often by combining various mechanical, chemical and thermal processes. Other classifications of recycling routes also deserve mentioning. For example, if the recycled material is of lower value (or quality) than the original product, this is termed down-cycling. Today, existing textile recycling routes are in most cases down-cycling. Clothing and home textiles are down-cycled into, for example, industrial rags, low-grade blankets, insulation materials and upholstery. In contrast, if a product from recycled material is of higher value (or quality) than the original product, it is termed upcycling. [1]

IV. RECYCLING OF COTTON WASTE TO PRODUCE REGENERATED FIBER

The global fiber production was around 90 million tons in 2014. Fiber production expected to increase with the rapid growing population combined with fast fashion change. Cotton is the mostly used fiber and considerable attention is given to recycle of the cotton waste. To date mechanical process was used to recycle the cotton waste. The bigger portion of recycled fibers were poorer quality and a small fraction was proper quality to mix with the virgin cotton. A possible solution was to improve the amount of recycled cotton that can be achieved by the use of chemical process. This regenerated cotton among other things could be utilized in textiles by developing a regenerated cellulose fibre. Viscose is the more commonly known RCF process. Viscose is produced by taking wood pulp and dissolving it in aqueous sodium hydroxide and carbon disulphide. The fibre is produced by wet spinning process. Limitations associated with viscose are the potential environmental concerns associated with the production of CS₂ a toxic gas as a side product of the dissolving solvent. Lyocell is an alternative to viscose, here the wood pulp is dissolved in N-methyl morpholine Oxide (NMMO) and the fibre is spun using a dry-wet spinning process. Typically Lyocell is considered to be an environmentally friendly alternative to viscose. Due to this mentioned limitation, a new range of dissolving solvent, over the past decade attracted significant interest. Ioncell is a regenerated cellulose fibre produced from wood pulp in a process similar to Lyocell however the NMMO is replaced with the ionic liquid 1,5-diazabicyclo[4.3.0]non-5-enium acetate (DBNAC). The mechanical properties are enhanced due to ability to achieve high draw ratios from IL. The mechanical properties are governed by many factors, one of which is the degree of polymerization. It is known that higher DP results in improved tensile properties, however both NMMO and aqueous sodium hydroxide and carbon di-sulphide are limited in their ability to dissolve high DP cellulose materials which has limited the chemical recycling of cotton lint.

4.1 Starting materials

1-Allyl-3-methylimidazolium chloride (AMIMCl>98%; lot no. 100319.2.1) was purchased from Io-Li-Tec, Germany. The IL was dried under reduced pressure at 85 °C to remove water prior to dissolution. The water content of AMIMCl was measured using a Karl-Fischer coulometer and was determined to be less than 0.8% for all dissolutions. Bleached soft wood kraft pulp (Pinuselliottii) (>90% cellulose, DP ~ 1092), and waste cotton lint (>92% cellulose, DP ~ 3133) were provided by the Cotton Research and Development Corporation (CRDC), Australia. All the cellulose samples were oven dried for at least 24 h at 105 °C prior to dissolution in order to remove the moisture.

4.2 Degradation of waste cotton lint into different DPs

Waste cotton lint with a starting DP of 3133 was systematically degraded using an alkali treatment to obtain cotton lint with different DPs as follows. 1.0 g of cotton lint was mixed with 100 ml of 10 wt% caustic soda (NaOH) solution in a glass beaker. The beaker was heated in a paraffin oil bath at a controlled temperature of 80 °C. The treated samples were thoroughly washed with distilled water until a neutral pH in the washing solution was obtained. A series of cotton lint samples with different degradation levels were obtained by having different treatment times of 5, 15, 30, 60, 120, 240, 480, and 960 min, resulting in DP values of 2700, 2543, 2410, 1996, 1704, 924 and 870 (±40). 3 measurements were completed and the average reported.

4.3 Dissolution of cotton waste lint in IL

A series of waste cotton lint samples with different DPs and wood pulp were dissolved in the ionic liquid AMIMCl under Nitrogen environment. All the dissolution experiments were carried out at 100 °C. After the desired cellulose amount is dissolved (2.0 wt.%), a clear and viscous solution was obtained. The complete dissolution was observed and verified using a Nikon 80i eclipse polarizing light microscope (PLM). A dissolved solution was obtained when no crystallinities in the cellulose solution were observed.

4.4 Preparation of regenerated fibres from the cotton lint waste

The fibre spinning was carried out using a simple laboratory setup at 40 °C. The polymer solution was degassed prior to spinning in order to remove any air bubbles contained in the spinning solution. The desired cellulose solution (spinning dope) was then filtered using ultra fine stainless steel filter (180µm) and transferred into a glass syringe (internal diameter of 10.5 mm) and mounted onto a syringe pump. The temperature of the spinning dope was maintained at 40 °C by a heating jacket attached to the glass syringe. The spinning dope was then extruded into a water bath through a 22G (internal diameter of 0.152 mm) at a fixed flow rate of 60 ml/h. After the desired coagulation time (10 min), the undrawn proto fibre was transferred into a second water bath to wash the fibre. Then, the washed fibre was completely dried at room temperature before the characterization. Table 1 shows the DP of both starting cotton lint and RCFs.

Table I: Dissolution times and DP of RCFs from waste cotton lint samples. [8]

DP of the starting cotton lint	Dissolution time in the IL (minutes)	DP of the RCF
3133±32	390	2680±26
2700±28	365	2124±20
2543±28	330	2025±20
2410±34	320	1894±22
1996±22	285	1425±20
1704±18	270	982±14
1070±16	220	904±15
924±12	190	646±12
870±14	180	495±14

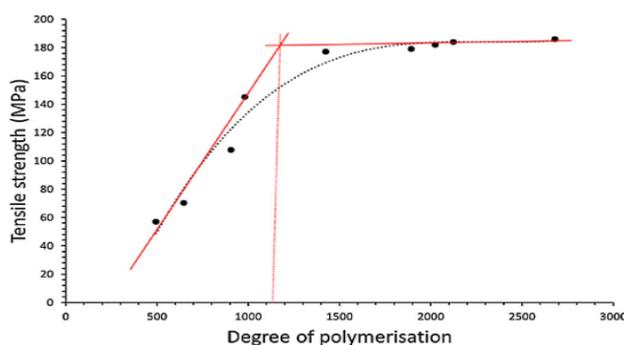


Figure 1: Change of tensile strength as a function of cellulose DP.[8]

Fig. 1 shows the tensile strength of RCF from waste cotton lint as a function of DP up to DP values of 2700. The tensile strength shows a linear relation with DP up to a DP value of 1150. Beyond DP values of 1150, no significant improvement in tensile strength occurs. It is known that increased molecular weight improves the tensile strength by enhancement in chain entanglements, findings suggest that beyond a DP of 1150 chain entanglements no longer contribute to tensile strength. The trend for DP and tensile strength measured here is a significant finding in terms of recycling high DP cotton waste to produce high strength RCFs since as the DP of the cellulose increases so does the time required for dissolution as does the viscosity of the cellulose/IL solution making spinning more troublesome if not impossible. Therefore from these findings it can be concluded that there is no benefit in terms of tensile properties of the regenerated material in using cellulose with a DP above 1150.[8]

V. VEGETABLE OILS

Vegetable or plant oils represent a renewable resource that can be used as reliable starting material to access new products with a wide array of structural and functional variations. The abundant availability and the relatively low cost make plant oils an industrially attractive raw material for the plastics industry. Naturally occurring plant oils and fatty acids derived thereof, are considered to be the most important renewable feedstock processed in the chemical industry and in the preparation of bio-based functional polymers and polymeric materials. The annual global production of the major vegetable oils (from palm trees, soybeans, rapeseeds, cotton, sunflower, palm kernel, olives, and coconuts) amounted to 84.6 million tons (Mt) in 1999/ 2000 and increased to 137.3 Mt in 2009/2010 (an increase of 62%). The production of fatty acids is the highest volume oleochemical process and accounts for about 52% of industrially used oils and fats. The world supply of fatty acids has almost doubled from 2001 to 2008. The main constituents of plant oils are triglycerides which are the product of esterification of glycerol with three fatty acids. Fatty acids account for 95% of the total weight of triglycerides and their content is characteristic for each plant oil. These triglycerides contain several reactive sites, such as double bonds and ester groups, opening up various possibilities to tailor new structures.

5.1 Structural applications

Vegetable oils have been extensively used for the production of polymer composites incorporating organic or inorganic particles or fibers, both synthetic and natural, and sized from the macro- to the micro- to the nanoscale. Thermoplastic composites and nanocomposite with glass or carbon fibers and with a variety of nanofillers (gold, nanotubes, ceramics, silica, etc.) have also been described as useful materials for injection molding and laminate technologies. In this case the thermoplastic polymers, typically, polyesters, polyamides, polyesteramides and polyurethanes are prepared from linear di-functional monomers produced by chemical transformation of vegetable oils. The most significant example is Nylon 11, a polyamide prepared from the 10-undecenoic acid obtained by pyrolysis of castor oil which is used in the production of automotive and engineering components. It is worth noting that this polyimide has also been used to prepare fibers for textile applications. Referring to the applications of these plant oil based composites most of them are tailored for structural applications in which low cost and sustainability issues are determinant over the material performance. A successful example is the development, by Ash-land researchers, of a polyester resin based, in part, on soybean oil and corn ethanol. This resin was first used to manufacture sheet molding compound composite panels that were used in John Deere tractors and harvesters. Functional materials for special applications have also received much attention and thus several plant oil based-composite coatings, adhesives, foams and shape memory materials have been developed

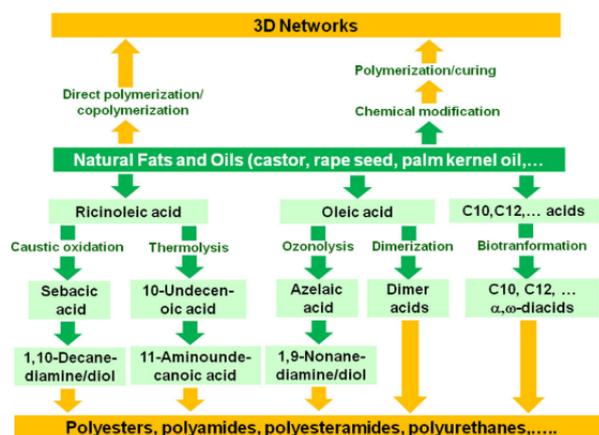


Figure 2: Main approaches to obtain thermoplastic and thermosetting materials from triglycerides and triglyceride-derived building blocks. [2]

5.2 Paints, coatings and adhesives

Vegetable oils have been used as binders or additives in paints and coatings for many centuries, dating back to the days of cave paintings. The primary use of vegetable oil in coatings is as drying oil. Drying oils are highly unsaturated oils that will oligomerize or polymerize when exposed to the oxygen in air, usually in the presence of a catalyst. The result is an increase in the molecular weight as a consequence of crosslinking. This led to the development of renewable resources based coating formulations with improved performance. Vegetable oil derivatives as value added polymers/monomers have found enhanced applications as environment friendly hyper- branched or waterborne coating materials that offer improved performance and reduction or elimination in the use of volatile organic solvents. Oil coatings are used to finish wood carving, to stain and finish wood decks, to coat cedar shingles, and in other applications for which penetration is desired and a slow cure rate is not a significant problem. The use of natural plant oils in the production of adhesives has been the focus of much research. Adhesives have been synthesized from soybean-oil-based polymers from different chemical pathways, exhibited thermo-physical and mechanical properties that are competitive with those of petrochemical based adhesives. Among the different classes of adhesives, pressure-sensitive adhesives are one of the most widespread types and represent a potential application that would benefit from the use of renewable materials. Self-adhesive tapes, labels, stamps and sticky notes are ubiquitous in everyday life and can be found everywhere (electronic industry, automotive parts, etc.). They adhere by simply applying pressure to a huge variety of materials and often the bond is reversible. The main advantage of pressure sensitive adhesives compared with other type of adhesives is the convenience of use. There are no storage issues, no mixing or activation necessary and no waiting is involved.

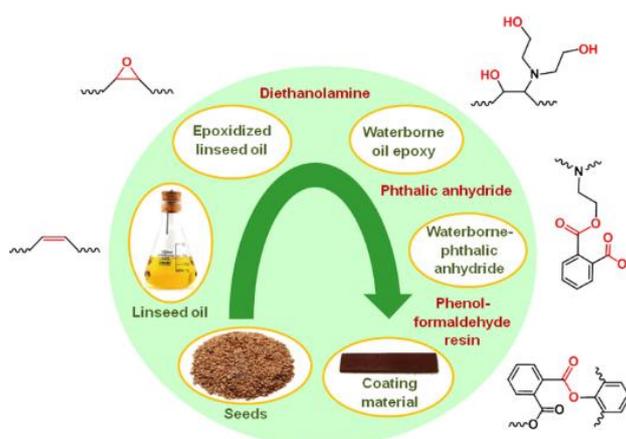


Figure 3: Preparation of waterborne coating material from linseed oil. [2]

5.3 Biomedical applications

Applications of vegetable oil-based polymeric materials are not restricted to the industrial arena and can also be extended to a variety of biomedical applications as surgical sealants and glues, pharmacological patches, wound healing devices, and drug carriers to scaffolds for tissue engineering. This is mainly because vegetable oil is a bio-based raw material that can be metabolized in the human body, and therefore materials

derived from them are potentially biocompatible. Moreover the incorporation of vegetable oil moiety can enhance the biodegradation of the material. In fact, they have been attractive for several biomedical applications requiring materials that range from soft to hard. For example, poly(glycerol sebacate) has been used in several soft tissue engineering applications such as retinal, nerve, vascular and myocardial repair, as well as adhesive sealant.[2]

VI. RECYCLING OF FIBER REINFORCED COMPOSITE

Fibre reinforced resins, thermosets as well as thermoplastics, are increasingly used to replace metals in numbers of industrial, sporting and transport applications. One of the biggest challenges posed by fibre reinforced composites is their recycling. Environmental legislation is becoming more and more restrictive, and just the environmental impact of these materials disposed in landfills is accelerating the urgency to reach more industrial scale solutions to the recycling of composites. Landfill is a relatively cheap disposal route but is the least preferred waste management option under the European Union's Waste Framework Directive, and opposition to it is expected to increase over the coming years; it is already forbidden in Germany, and other EU countries are expected to follow this route. Many different recycling techniques have been studied for the last two decades: mechanical processes (mainly grinding), pyrolysis and other thermal processes, and solvolysis. Some of them, particularly pyrolysis, have even reached an industrial scale, and are commercially exploited: for example, ELG Carbon Fibre Ltd. (ELGCF) in United Kingdom use pyrolysis, Adherent Technologies Inc. (ATI) in USA use a wet chemical breakdown of composite matrix resins to recover fibrous reinforcements and, in France, Innoveox propose a technology based on supercritical hydrolysis. Pyrolysis is the most widespread technology as it is a proven and heavily used process in the chemical industry. However as the fibres degrade at high temperatures, solvolytic processes have attracted increasing interest, especially over the last decade. A complete evaluation must be carried out in order to compare the different technologies in terms of environmental impact, efficiency and commercial viability. It is also quite clear that the choice of the separation/recycling method depends on the material to recycle and on the reuse applications of the fibres in particular. The recovered products, mainly fibres and products from resin decomposition, are most often systematically characterised and show that they can be reused. In particular recycled carbon fibres (rCFs) (often discontinuous as the materials require to be cut in smaller pieces before treatment) have been incorporated with success in a few trials. Recycled glass fibres (rGFs) can also be reused as fillers in thermoplastics or short fibres in BMC (bulk moulding compound), mainly. On the other hand, fractions containing products from resin degradation by solvolysis have received very little consideration. Pyrolysis products from the resin have been mainly considered as a source of energy to feed back into the process.

6.1 Mechanical recycling

This technique consists of grinding materials more finely after a first crushing or shredding step into smaller pieces; the latter is common to all the recycling techniques. Generally different sizes of recyclates can be recovered and separated by sieving into resin-rich powders (and rich in fillers for SMC materials for example) and fibres of various lengths that are still embedded in resin. Flakes of materials can also be found in the recyclates. Mechanical grinding has been more applied to glass fibre reinforced composites, in particular SMC (sheet moulding compound) and BMC, but work on CFRCs (carbon fiber reinforced composite) also exists.

6.2 Thermal processes

Thermal processes include pyrolysis, fluidized-bed pyrolysis and pyrolysis assisted with micro-waves. These techniques allow the recovery of fibres, eventually fillers and inserts, but not always the recovery of valuable products from the resin (i.e. monomers that could be reused to produce resins). The resin is volatilized into lower-weight molecules and produces mainly gases such as carbon dioxide, hydrogen and methane for example, and an oil fraction, but also char on the fibres. The processes operate between 450 °C and 700 °C depending on the resin. The lower temperatures are adapted to polyester resins, whereas epoxides or thermoplastics, like PEEK for example, require higher temperatures.

6.2.1 Pyrolysis

The most studied thermal process is pyrolysis performed in absence or in presence of oxygen, and even more recently in presence of steam. The matrix degradation produces an oil, gases and solid products (fibres, eventually fillers and char). The fibres are contaminated by this char and require a post-treatment in a furnace at 450 °C at least to burn it, for example for GFRC (glass fibre reinforced composite). This also leads to a higher degradation of the fibres. This process has been more developed to recycle carbon fibre reinforced matrices and has reached commercially exploited industrial scale. Glass fibres suffer from the high temperatures and their mechanical properties are decreased by at least 50%, especially as the minimal process temperature is 450 °C.

Carbon fibres are less sensitive to temperature but they can be contaminated by a char-like substance remaining from the degradation of the resin, which prevents a good bond with a new resin. At 1300 °C this substance is completely removed and the fibres are perfectly clean with highly activated surface, but their strength is significantly reduced.

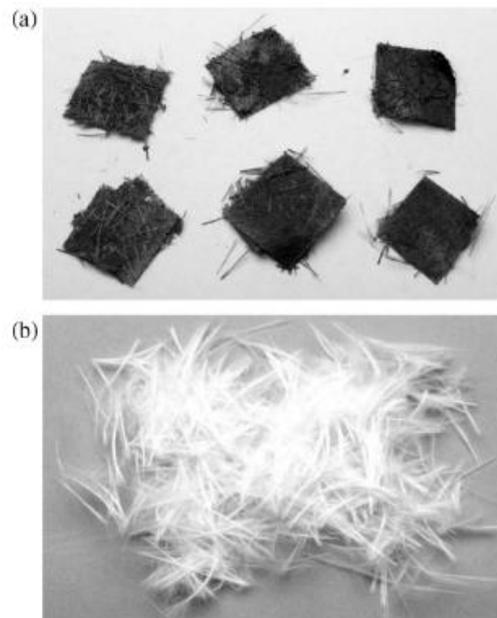


Figure 4: (a) Solid pyrolysis residues, (b) recovered fibre after separation [9]

6.2.2 Fluidized-bed process

Fluidized-bed process has been applied to the recycling of glass fibre reinforced composites (GFRCs) and CFRCs. This pyrolysis-based process uses a bed, of silica sand for example, fluidized by hot air so conditions are oxidant. It enables a rapid heating of the materials and release the fibres by attrition of the resin. As in classical pyrolysis, a small amount of oxygen is required to minimize char formation. A rotating sieve separator was implemented in Pickering's process to separate fibres from fillers of recycled GFRCs. The organic fraction of the resin was further degraded in a secondary combustion chamber at about 1000 °C, producing a clean flue gas (for energy recovery). At 450 °C glass fibre tensile strength was reduced by 50%, while at 550 °C the reduction achieved 80%. Carbon fibres show a lower strength degradation of about 25% when processed at 550 °C. Analysis of their surface showed that the oxygen content resulted in a little reduction, indicating that the fibres have good potential for bonding to a polymer matrix.

6.2.3 Micro-wave assisted pyrolysis

Microwave-assisted pyrolysis has also been considered over the last ten years to recover carbon and glass fibres by Lester et al. at the University of Nottingham, by the American company Eltron Research, and more recently by Åkesson et al. at the University of Borås. The main advantage of microwaves is that the material is heated in its core so that thermal transfer is very fast, enabling energy savings. Microwave-assisted pyrolysis heats composite wastes in an inert atmosphere, degrading the matrix into gases and oil. The first application of this heating method to recycle composites was studied by Lester et al. in 2004. They used quartz sand to suspend the samples made of carbon fibres and epoxy in a microwave cavity and glass wool to prevent solids leaving the cavity. Microwave treatment was also used by the American company Firebird Advanced Materials at the same time, but they stopped their activity due to a lack of investors in 2011.

6.3 Solvolysis

Solvolysis consists of a chemical treatment using a solvent to degrade the resin. This technique was first considered about 30 years ago and applied to unsaturated polyesters (UP) and SMCs (sheet moulding Compound) as UP is one of the most widely used thermoset resins and in particular in SMCs. Hydrolysis between 220 and 275 °C either with or without added solvent or catalyst was used by Kinstle et al. in the 1980s to degrade UP into its monomers (carboxylic acids and glycols) and a styrene–fumaric acid copolymer. Since then many different conditions and solvents were tried in order to recycle thermoplastics, thermosets and their fibre reinforced composites. Solvolysis offers a large number of possibilities thanks to a wide range of solvents,

temperature, pressure and catalysts. Its advantage, compared to pyrolysis, is that lower temperatures are generally necessary to degrade the polymers, in particular UP and epoxides. However when supercritical conditions, of water for example, are reached, reactors can become expensive as they have to withstand high temperatures and pressures, as well as corrosion due to modified properties of the solvents. A reactive solvent, sometimes in mixture with a co-solvent or with a co-reactive solvent, diffuses into the composite and breaks specific bonds. It is therefore possible to recover monomers from the resin and to avoid the formation of char residues. Depending on the nature of the resin, more or less high temperatures and pressures are necessary to degrade the resin. Polyester resins are generally easier to solvolyse than epoxy resins and so require lower temperatures to be degraded. During the last decade this method has been more intensively used to recycle composites, in particular CFRP, as the recovery of carbon fibres has become a commercial interest.[9]

VII. REUSING OF TIRE TEXTILE WASTE

Population increase and increasing need for vehicles have led to annual production of a large number of tires all around the world. About 17 Million tons of tires per annum reach their end of life cycle, all around the world. It is predicted that till 2030, using tires will be increased by about 20%, i.e. production of 1200 Million of the End of Life Tires (ELT), annually. These tires are disposed as wastes after end of their lives. Therefore, increasing volume of tire production has resulted in worldwide concerns about negative effects of these wastes on the environment and humans' health. Researchers in all scientific fields are trying to use these huge resources of energy. In general, there are four options to handle ELT: reuse (5-23%); recycling (3-15%); sending to landfill (20-30%); and, energy recovery (25-60%) . Generally, three main materials are produced from ELT, namely, rubber, steel wires and textile fibers (approximately 10% by weight of ELT). Granule is the main material resulted from the treatment process of ELT. These materials are then used as a basis in manufacturing new materials, such as different kinds of tires, plastic parts, concrete, asphalt, etc. In this process, textile fibers and reinforcement wires in tires are separated as discard. Separated steel wires are generally simply used by steel production factories in manufacturing new virgin steel. The possible use of these fibers as a spread reinforcement in cementitious composites has been recently investigated. Moreover, some researchers used these wires to reinforce the soil. On the other hand, WTTF separated during treatment process are classified as special wastes (EWC code 19.12.08) which have to be burnt or buried. In recent years, some researchers have tried to reuse these wastes and prevent them from being burnt or buried.[10]

7.1 End of life tires characteristics and valorization

Tires are made up of four main parts: (i) the tread, designed for contact with the ground and to ensure the proper friction; (ii) the carcass, the structural part of the tire on which the tread is vulcanized; (iii) the shoulder, which minimizes the effects of irregularities of the terrain and transfers the load due to braking and oversteering under acceleration; and (iv) the heels, to fit the casing to the rim. Regarding the constituent materials, tires have a mixed composition of carbon black, elastomer compounds, steel cord, fibers, in addition to several other organic and inorganic components. Table 2 shows a brief overview of this composition.

Table II: Average composition of a tire. [11]

Ingredient	Rubber/Elastomer	Carbon Black	Metal	Textile	Zinc Oxide	Other
Passenger Car	47%	21.5%	16.5%	5.5%	1%	8.5%
Lorry	45%	22%	23%	3%	2%	5%
Off the Road	47%	22%	12%	10%	2%	7%

Each compound contributes to the particular characteristics of the tire, so as to promote longer life and a particular level of friction. The most common treatment for ELTs is the shredding in dedicated mills. The output of the treatment process is thus a shredded material of various sizes and types, depending on the intended uses: rubber chips or granules (about 70%), steel fiber (5-30%) and textile fiber (up to 10%).

7.2 Potential reuse scenarios for tire textile fiber

In Europe the law defines the legal framework and assigns the responsibility to organize the management chain of ELT to the producers (tire manufacturers and importers). The crucial steps are collection, sorting, transformation and recovery in authorized treatment companies. In recent years, progresses in the recovery of materials from ELTs have been done and currently the main application is energy recovery (as fuel in the cement kiln). The reuse of secondary raw materials is mostly exploited in civil engineering. Recycled

rubber is reused in modified asphalt mixtures; additives for concrete; lightweight fillers in infrastructure; safety barriers, bumpers, artificial reefs, etc. Steel fibers from ELTs are sent to electric arc furnaces where they are used as secondary raw material by melting or to replace anthracite and coke as reducing elements of metal oxides. In addition, some studies have shown affordable use of steel fibers from ELTs as reinforcement in concrete. The textile fiber, derived from the disposal of tires, it is until now classified as waste material. Textile fibers generally contain rubber impurities resulting from the shredding of the tire. The percentage of rubber present in the fibrous material varies from 5 to 20% by weight based on the treated type of tire. The research for the reuse of the textile fiber starts from the idea that it is necessary to separate the residual rubber component so as to obtain a "pure" material in order to reuse in an alternative application.[11]

7.3 Waste tire textile fibers using as reinforcement of recycled polypropylene

Textile fibers represent about 10% by weight of the ELTs, thus in Europe, about 320.000 tons per year of dirty textile fibers represent about 10% by weight of the ELTs, thus in Europe, about 320.000 tons per year of dirty fibrous material must be disposed as special waste. This leads to the generation of negative impacts on the environment, economic losses and public costs. Beside the issue of ELTs disposal, there is the post-consumer plastic disposal issue that deserves equal attention. Typically, post-consumer plastic wastes are composed by mixed plastics of unknown composition and are potentially contaminated by organic fractions (such as food remains) or non-polymer inorganic fractions (such as paper). Plastic wastes account for about 12% to 16% of global wastes. Recycling is not always feasible, due to problems to separate the mix composed by numerous types of polymers with different mechanical and technological characteristics. Concerning polypropylene (PP), its recycling and reuse have been investigated in several literature studies. It was observed the changes of rheological and mechanical properties for recycled PP. An important change in chemical structure and rheological values after different injection molding cycle was also investigated and have proved the good recyclability of PP by showing a slight decrease of the tensile strength (-15%) with a 100% recycled PP compared to a pure PP. A possible solution to the above-mentioned weaknesses is the insertion of reinforcing fibers in the polymer matrices. Different studies showed how the use of fibers increases the properties of waste PP. The fibers can be natural (e.g., cellulose, jute, hemp, straw, switch grass, kenaf, coir and bamboo), glass fibers, carbon, etc. However, it is hard to find information about the possible reuse of ELT fibers. Studies show that the fibers, mainly consisting of a blend of polyester, rayon and nylon fibers, have yielded positive results in different applications. The use of waste textile fibers as reinforcing material for PP used in the production of car bumpers. Even in this case a positive result has been observed. Fibers give to the modified PP a greater resistance to bending and an acceptable impact strength, and contribute to increase the elasticity modulus.[12]

VIII. POTENTIAL APPLICATION OF RECYCLED NONWOVEN

Thermal insulation is a key element in the building sector, it minimizes energy consumption and guarantees thermal comfort. Four nonwoven fabrics based on acrylic and wool waste were made using the needle punching technique, and tested in terms of thermo-physical properties. Results show that all developed nonwovens have an excellent insulation performance, the thermal conductivity is in the range of 0.03476–0.04877 W/(m/K); these values are comparable with that of conventional insulation materials. The lowest value of the thermal conductivity is observed for the nonwoven made from washed wool W_r (0.03476 W/m/K). In order to evaluate the thermal performance of manufactured nonwoven, a reduced-scale thermally controlled cavity was used; each wall of the cavity is outfitted with one nonwoven. The comparison is based on the outside surface temperature walls. The fixed inside surface temperature was 36°C; however, the outside surface temperature was less than 19°C. This result is in accordance with the obtained thermal conductivity values and confirms that materials based on textile waste have competitive thermal properties and could be used in building insulation materials.

8.1 Manufacturing nonwoven insulation

The textile waste cuttings are taken from a Moroccan textile. After the waste collection stage, they were sent to a shredding company. The textile waste consists of acrylic and wool. The final form of waste is shown in Figure 5. The nonwoven webs were prepared according to the needling technique, It is defined as a method of consolidating the mats by the repeated insertion of barbed needles into the fibrous web. This process consolidates the structure of the fibrous web without any binder by interlocking fibers.



Figure 5: Shredded textile waste. [13]

8.2 Thickness, mass per unit area, density and air permeability

The thickness (t) of samples were measured according to standard ISO 9073-2 using thickness Lab 1880. The mass per unit area of the sample is measured according to standard EN 12127 using an electronic balance, five samples of 100cm^2 were taken with using a cutting dispositive. Five random readings were taken for measuring thickness and area weight. Bulk density ρ [kg/m^3] is defined as the ratio of the mass per unit area [kg/m^2] and thickness [m]. This parameter is correlated with the thermal capacity of the material. The air permeability of a building characterizes the sensitivity of the building to parasitic aeraulic flows caused by leaks in its envelope, or more simply the amount of air entering or leaving through it. It is quantified by the value of the leakage flow passing through the envelope under a given pressure differential. In this work the air permeability was determined by using AIR-TRONIC according to the ASTM D737-04. The test was conducted at pressure difference of 200 Pa for a surface area of 10cm^2 . The measurement result of air permeability is based on equation (1)

$$k = \frac{Q}{S \cdot t} \quad (1)$$

where k is rate of flow $\text{L}/(\text{m}^2 \cdot \text{s})$, Q is volume of flow of fluid through the sample [L], t is time [s] and S is the cross-sectional area [m^2].

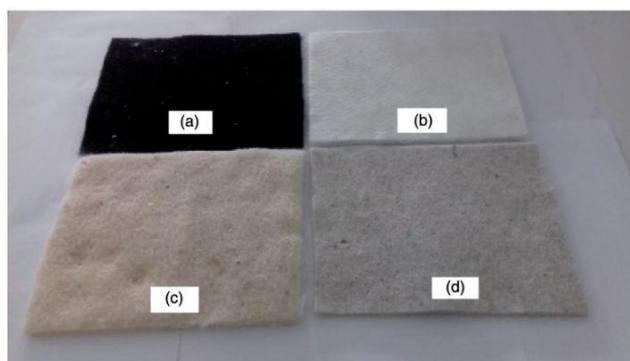


Figure 6: Flexible insulating nonwovens; a: 100% acrylic knitting waste, b: 100% acrylic spinning waste, c: 100% washed wool, d: 100% carpet waste wool. [13]

8.3 The thermal conductivity and thermal resistance

The thermal conductivity λ of material is defined as the amount of heat crossing a unit area of the material per unit time per unit temperature gradient. The guarded hot plate apparatus lambda-Meter EP500e was used for measuring the thermal conductivity as per the EN 12667 standard. It measures the sample thickness e [m] of the inserted sample, the temperature difference ΔT [K] over the sample and the heat flux Q [W/m^2] which is equivalent to the electrical power $P=U \cdot I$ of the measuring heating. The thermal conductivity λ [$\text{W}/(\text{m} \cdot \text{K})$] is determined based on the defined measurement area S [m^2] and the one-dimensional thermal conduction as

follows.

$$\lambda = \frac{Q \cdot e}{S \cdot \Delta t} = \frac{U \cdot I \cdot e}{S \cdot \Delta t} \quad (2)$$

Sample size used for measurement was 200mm × 200mm. In this study, the measuring temperature was 10, 25 and 40°C. Moreover, the temperature difference between the hot plate and the cold plate is set at 15°C in all measurements. The thermal resistance is expressed by the following relationship

$$R_{th} = \frac{e}{\lambda}$$

where e [m] is the thickness of the sample, λ is the thermal conductivity [W/(m.K)].

8.4 Thermal performance of the nonwovens using test cell

The thermal performance of walls out-fitted with the studied insulating mats is measured using a cavity at reduced scale termed here as test cell. It is a cubic box which held 0.4m × 0.4m × 0.4m walls. Each wall contains one type of insulation. The insulating mats are installed between two wood layers as shown in Figure 7. Each layer of the wood and insulating mats has a thickness of 1 cm. The heating of the test cell is provided by an incandescent bulb mounted in a black window protection placed at the center of the test cell. Later, this cell is housed in a conditioned large scale local in order to control the exterior air temperature and boundary conditions. Under this arrangement, the interior of the test cell simulates the outdoor environment of a real building, while the exterior of the test cell simulates the indoor environment of a real building. [13]



Fig: 7: Schematic of the wall showing the location of the insulating mats. [13]

IX. ENVIRONMENTAL IMPACT OF TEXTILE REUSE AND RECYCLING

The global demand for textile products is steadily increasing, a trend likely to continue due to population growth and economic development. Meanwhile, the textile industry is facing tremendous environmental and resource challenges. Sixty-three percent of textile fibres are derived from petrochemicals whose production and fate give rise to considerable carbon dioxide (CO₂) emissions. The remaining 37% is dominated by cotton (24%), a thirsty plant associated with water depletion- the desiccation of the Aral sea being the most infamous example and toxic pollution, due to intensive use of pesticides. For most categories of environmental impacts, later stages in the textile production process give rise to even larger impacts. Wet treatment processes (dyeing, finishing, printing, etc.) are major sources of toxic emissions, and spinning of yarns and weaving/knitting of fabrics most often rely on fossil energy use, causing emissions such as CO₂ and particulates suggest greenhouse emissions, water use, toxic chemicals and waste are the main environmental issues facing the textile industry. The impact per garment use in a western country (in this case, Sweden) must be reduced by 30-100% by 2050 if the industry is to be considered sustainable with regard to the planetary boundaries. Because of the aforementioned challenges, there is regulatory interest in increasing textile reuse and recycling, which would move the treatment of textile waste further up in the waste hierarchy, consistent with the EU directive on waste (European Commission (EC), 2008). Increased textile reuse and recycling could potentially reduce the production of virgin textile fibres and, in the case of reuse, also avoid engineering processes further downstream

in the textile product life cycle, and thus reduce environmental impact.[1]

Ideally, recycling and, even more so, reuse of textiles can reduce the production of new textiles from virgin materials and hence reduce the use of water, energy and chemicals during the production chain. In addition, many risks associated with chemicals in textiles may be avoided by reducing superfluous consumption of textiles in the first place, especially those with unnecessarily dangerous chemicals.[14]

The landfilling scenario is not an environmental friendly solution, since fibers, like many other synthetic polymers, are not biodegradable. Landfills are facilities which, by nature, produce several impacts on the environment, such as land use or generation of liquid and gaseous contaminants. The incinerating of waste is the process of recovery energy of which 40% is used to produce electricity. Though, this scenario in compare to landfilling, creates less environmental impact, it requires expensive machinery with higher investment cost hence less feasible in economically. Only Reuse and recycling scenario economically viable as it reduce using virgin fiber as well as concerns least environmental impact among three scenario.[12]

X. CONCLUSION

The use of cotton lint waste as a feedstock for regenerated cellulose fibres is a new way to utilize a larger percentage of the waste cotton material combined with the ability to produce a cellulose fibre with improved tensile properties. Nonwoven fabrics produced from textile waste belongs to optimum thermal conductivity that could be used as insulation of building materials. Renewable vegetable oils is the feedstock of large number of green products which could be substitute of petroleum based products. Recovered textile fibers from the end of life tire is now using as reinforcing of soil, recycled poly propylene composite. There are various process to recover fiber in the recycling of fiber-reinforced composite. The choice of the process depends on the type of resin and end use application of recycled fibers. There is a great potential for the textile recycling sector to contribute to the circular economy. It can reduce the production of new textiles from virgin materials and hence reduce the use of water, energy and chemicals in the production chain. However, textile recycling is still facing a number of challenges, such as limited practical technologies for recycling various types of fibres, technical problems related to the complexity of clothes, and immature markets. To solve this problem government and business society should reflect more focus to provide research activities for effective reusing and recycling of waste material in addition to the substantial socio-economic advantage and sustainable environmental improvement.

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