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REUSING AND RECYCLING TEXTILE MATERIALS: AN OVERVIEW

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ABSTRACT:
The world has been facing a growing crisis in textile waste due to global population growth and improved living conditions, combined with a decrease in the life cycles of textile products. Textile waste recycling is one of the key aspects to consider in moving towards circular economy in textiles. Worldwide, 75% of textile waste is landfilled, while 25% is recycled or reused. Landfilling of textile waste is a prevalent option that is deemed unsustainable. Promoting an enhanced diversion of textile waste from landfills demands optimized reuse and recycling technologies. Reuse is the more preferred option compared with recycling. Textile waste can affect people's lives economically and environmentally. Producing apparel from natural or synthetic origin can produce pollutants and waste at each stage. Various textile reuse and recycling technologies are available and progressively innovated to favor blended fabrics. This paper aims to establish reuse and recycling of textile materials to manage textile waste.
INDEX TERMS- OHAS, Textile Industry, Common Hazards, Textile Waste, control measures

1.INTRODUCTION

The growth of world population, economic development, and the fast fashion markets have caused an increasing global demand for textile products. (Sandin and peter 2018). Rapid fashion cycles, global scale of production, and overconsumption have contributed to the recurrent generation of textile waste. (Echeverria et al,2019) Textile wastes are disposed together with non-organic mixed wastes, which eventually find their ways to landfills or incineration. Europe recycles only 25% their textile waste and the rest is either landfilled or incinerated (Haslinger et al., 2019). In the USA, textile waste generation is 17 MT/year (EPA ,2020); however, only around 15% of total waste is recycled. These numbers continue to increase until economically, and practically feasible solutions are developed to reduce the waste generation or by closing the loop that turns waste into new products. (Navone et al 2020) Synthetic materials are well suited for incineration because they are highly combustible and produce high amounts of heat when burned (Newell ,2015). However, the concept of circular economy cannot be realised with energy recovery from waste (Wanassi et al,2016). Therefore, textile wastes have to be recirculated in the manufacturing process through recycling or remanufacturing. Landfilling and incineration not only create environmental pollution but also, a waste of valuable resources (Lv et al,2015). Textile industry is still in the early stages of recycling where many valuable polymers are underutilised or not utilised at all (Echeverria et al. 2019). However, the volume of textile wastes ending up \in landfills is rapidly increasing, and hence, the requirement of efficient and economical recycling technologies is critical in order to close the loop of material flows. Fabric-to-fabric recycling in a closed-loop system is rarely demonstrated. As there are limited natural resources, it is vital to consider how to manage these resources efficiently by diminishing consumption of virgin raw materials through the reusing and then recycling of textiles regarded as waste, which would facilitate a sustainable approach to textile waste management. Although the recycling of textiles has improved in recent years, it is still not commonly commercially viable. In Europe, a quarter of waste textiles are recovered or recycled, while the rest is disposed of in landfills, only 1% return to the clothing cycle. Globally, approximately 75% of textile waste is disposed of in landfills, 25% is reused or recycled, and less than 1% of all textile is recycled back into clothing. In this respect, advancing reuse and recycling technologies for textile waste in diverting waste from landfill is crucial. Hence, textile reuse and recycling are vital in promoting this innovative act.

2.TYPES OF TEXTILE WASTE

Textile waste generated by the apparel industries is gen early classified into three categories: pre-consumer, post-consumer, and industrial waste. (Wang Y,2006) Pre-consumer textile waste refers to manufacturing waste generated when natural, synthetic, or blended fibres are processed into yarns, fabrics, and finished garments, footwear, interior, or technical textile products. Pre-consumer waste is easier to recycle than post-consumer waste as it tends to be more uniform with fewer unknown con dominants. Unsold stock and returns from offline and online sales are also included in pre-consumer waste. (Official journal of the European union,2018) Unsold stock and returns are considered by some industry specialists to be industrial waste since the flash ion industry must dispose of them. ion industry must dispose of them waste items should be avoided as much as possible and can only be disposed of in landfills when they are no longer useful. Clothes usually have different decorations, but tons, and accessories, and are commonly blended, making their recycling process more complicated. (Eppinger. E,2022). Post-consumer textile waste includes any apparel or fabric that has reached the end of its useful life and has been discarded, because it is worn out, has been dam aged, has been outgrown, or has fallen out of style· (Jestratyeic I,2023, Stanescu MD.2021) Finally, commercial and industrial users generate industrial textile waste, including carpets, hospital refuse, filters, conveyor belts, etc. Industrial textile waste is usually considered dirty waste. Burning or burial methods are very common for this category of waste. (Chavan R, 2023)

3.TEXTILES REUSE AND RECYCLING FABRIC

Generally, textile reuse and recycling could reduce environmental impact because it could potentially reduce virgin textile fibre production and avoid processes further downstream in the textile product life cycle'. Closed-loop recycling involves recycling of a material from a product and reusing it in a more or less identical product. open-loop recycling consists of recycling of a material from a product. Recycling technologies for fibres can be typically divided into primary, secondary, tertiary, and quaternary approaches. Primary approaches involve recycling in dust rial scraps. Secondary recycling involves the mechanical processing of a post-consumer product. Tertiary recycling involves pyrolysis and hydrolysis, converting plastic waste into chemicals, monomers, or fuels. Quaternary recycling refers to burning the fibrous solid waste and utilizing the heat generated (Ignatyev A 2008). Textile reuse has increasingly become a popular option in mitigating the negative impacts of textile waste on the environment. Textile reuse refers to the process of using or adapting textiles already in existence, rather than creating new products. It is widely accepted that reuse is more beneficial than recycling. (Fortuna LM et al,2017). Textile reuse is an increasingly popular practice that offers a variety of ways to extend the useful service life of textile products from their first owners to the next. This includes repair, re-purposing, upcycling, and donating, among many others, recycling textiles is a much more sustainable approach than incineration or landfilling which can negatively impact the environment. Textile recycling helps reduce water usage by converting waste materials into textiles that require less water and produce fewer emissions than new material. (Sanding 2018, Fortuna LM.et al,2017). Textile recycling is a critical part of modern waste management and can be classified into four categories: upcycling, downcycling, closed-loop, and open-loop recycling. Upcycling involves transforming materials into higher quality, or more valuable products; down cycling involves breaking the material down into lower quality products; closed-loop recycling consists of using recycled materials in the same product cycle; and open-loop recycling involves using recycled mate rials for a completely different purpose and often results in down-cycling. Each type of textile recycling plays a different but vital role in diverting waste from landfills. (Johnson et al,2020, Geyer) Open-loop recycling, e.g., turning plastic bottles into recycled polyester clothing, is currently a more common source of recycled textiles than closed-loop recycling. In contrast, closed-loop recycling involves reusing the material over and over again to create the same product, e.g., fibre-to-fibre recycling. (Mwanza ,021, Kushwaha MS.et al,2019)

4.TEXTILE RECYCLIING TECHNOLOGIES

4.1. Mechanical technologies

Mechanical recycling method can be divided into two paths based on the recycling mechanism applied. First path is the melt-extrusion process where shred ding, crushing, grinding of waste followed by melting, and re-extruding to obtain fibres for subsequently being re-spun into yarns or production of non-woven panels. Synthetic fabrics such as polyester or nylon can be cut into flakes and converted back to fibres by melt-extrusion either by direct extruding into fibres or by converting flakes into pellets or chips by pelletising, followed by melt-extrusion into fibres. (Shen et al,2010). The second method is thermo-mechanical processing, which is commonly used in open-loop recycling of plastic bottles into recycled polyester (or nylon) fibre. Thermo-mechanical technologies are a promising approach for textile recycling of thermoplastic materials such as polyester and nylon. The process involves mechanical shredding of the waste material, followed by heating, agitation, and filtration to break down the fibres and remove any impurities. This can result in a high-quality recycled material that can be used in various applications. (Dediu I et al,2022, Lindsrom F,2018)

4.2. Chemical technologies

Chemical recycling can also perform in two paths. It involves depolymerizing textile waste into oligomers and monomers and their subsequent re-polymerization. Depolymerization processes have become increasingly popular amongst waste management facilities when treating synthetic polymers. This process effectively breaks down the polymers into monomers or oligomers that can be more easily managed and re-used. Textile waste can be trans formed into valuable resins, like nylon and polyester. The depolymerization methods include various techniques such as hydrolysis, amino lysis, glycolysis, solvolysis, and metanalyses. (Jijun L et al,2021)

4.3. Biochemical technologies

Biochemical process of textile racy cling is an environmentally friendly enzymic treatment that breaks down polymers into monomers. Enzymes are biocatalysts that increase the efficiency of chemical reactions. (Piribauer,2019) Biochemical processes usually start with acidic or alkaline pretreatments, which break down the structure of fibres. Cellulose consists of two parts, amorphous and crystalline. Acidic pretreatment causes the hydrolysis of the amorphous part, and enzymes degrade the crystalline part. Acidic pretreatment works by breaking down the inter- and intra-chain bonds of the cellulose molecules, creating more space for enzymic treatment. As a result, it can significantly improve the conversion rate compared to traditional chemical methods and allow for more efficient use of resources. Alkali pre-treatment is an effective way to increase the efficiency of cellulosic bioconversion pro cesses. Alkali pre-treatment is usually carried out with a few different types of chemicals, such as sodium hydroxide, potassium hydroxide, and calcium hydroxide. (Kuo HS et al,2010) Cellulose enzymes can break cellulose chains in textile wastes into small sugar molecules and generate synthetic residue, which can be filtered and re-spun into synthetic fibres. (Shojaei et al,2012) However synthetic blended or dyed cotton do not efficiently react in enzymic hydrolysis, and therefore, an effective pre-treatment is needed beforehand. (Kuo et al,2010) Not only cellulose-based materials, but also synthetic materials such as polyester can be hydrolysed using bio chemical recycling methods, which breaks the ester link ages in the polymer chain and converts them into monomers. (Piribauer et al,2019)

4.4. Thermal technologies

Thermal recovery process refers to the combustion of wastes for energy production. As textile waste is composed of high amount of energy, that can be used as a raw material for energy generation (Pensupa et al,2017). Combustion, pyrolysis gasification, and incineration are considered as main thermal recycling technologies. Combustion involves a series of exothermic chemical **reactions** between a fuel and oxidant to produce heat. In pyrolysis, thermal decomposition of the organic material occurs in the absence of oxygen (Larrain et al.,2020). Pyrolysis can be applied into a mix of textile materials without prior sorting, and this process produces oil or gas, which can be used to fulfil the energy demand in various applications (Piribauer and Bartl,2019)

5.CHALLENGES OF TEXTILE RECYCLING

The global increase in clothing consumption and production has resulted in a significant increase in textile waste generation, posing alarming challenges in many leading countries. Textile waste is recognized as the fastest-growing waste stream in MSW across the globe (Bukhari MA 2018)**.** Despite the growing interest in sustainable textile recycling, many challenges and barriers still need to be addressed. Textile recycling is a complex process that involves various stages, such as collection, sorting, processing, and manufacturing. Each stage requires different equipment and expertise, which makes it difficult to develop a streamlined and efficient process. (Wang Y. 2010, Hole G,2019) Textile reuse, the most preferred option, suffers a shrinking market due to banning imported used clothing in some countries. Textile reuse and recycling to produce new products should be driven by economic incentives to make it feasible for the operating industry. Sustainable blended materials made from recycled fibres are innovative to reduce environmental impact. (Textile Exchange,2020) Another challenge is the need for more consumer awareness and participation. Many people are unaware of the environmental impact of textile waste and the benefits of recycling. As a result, they may not prioritize textile recycling and dispose of textiles in their general waste. Consumers' behaviour toward fashion industry products is different from their behaviour toward other products such as household appliances. It is more common to change household appliances when they break but people change clothes for trivial reasons such as going out of fashion. (Watson D et al ,2015) In recent years, companies have begun to take action by implementing initiatives to reduce textile waste, such as encouraging the use of recycled materials and implementing more sustainable practices in the production process. These changes can help to protect the environment and create a more sustainable fashion industry. (Bell. A,2020) There are several economic and policy barriers against the effective implementation of textile recycling. One of the main economic barriers is the high cost of recycling textiles. Compared to virgin materials, recycled textile materials are more expensive, making it less cost-effective for manufacturers to use them. Additionally, the market for recycled textiles is small and fragmented, making it challenging for producers to find buyers for their recycled materials. (Eppinger E,2022)

6.PRACTICES RECYCLING OF TEXTILES WASTE

Textile recycling faces various obstacles in terms of cost, time, and technology. Strategies and policies have been established in different regions that will provide both environmental protection and economic efficiency. (Vadicherla T et al,2014) There are myriad organizations offering certification for sustainability conscious brands. For instance, Blaesing Technologies AG, a Swiss-based organization, have labelled products with their production pro cesses, energy inputs, and air emissions audited. Each component used in the process is examined from an ecotoxicological point of view and possibilities to reduce consumption are evaluated. Textile waste treatment units are expected to follow verifiable procedures. The Blaesing certificate is given to garments and accessories with socially sensitive features. Oeko-tex labelling can be used for textiles that have been tested for harmful substances and, until recently, Levi's Eco collections are made of organic and recycled cotton. Levi's Waste-Less Jeans contain 29% recycled plastic from post-consumer waste. H&M introduced their Conscious Collection using organic cotton fibres in the mid-1990s. In their second Conscious Collection, they produced party dresses using recycled polyester and organic cotton. Plastic tote bags in H&M's stores also contain recycled polyethylene from 50% pre-consumer and 50% post-consumer waste. (https://www.esprit. Nike produced sportswear from recycled plastic bottles for the 2010 FIFA World Cup. It also briefly used Fly knit technology that reduced the amount of waste in knitted fabrics in its shoes. Adidas introduced the Fluid Trainer as the "most sustainable shoe ever." However, it did this by using 50% recycled material in the shoe upper and some other parts contained 10% or 20% recycled material. Esprit was the first company to manufacture beach wear from recycled nylon. They used 70% recycled nylon and 30% Lycra in the beachwear they presented with Beachwear Collection 2012. Then, in the Beachwear Collection 2013, they increased the rate of recycled nylon to 82%. Eco-friendly Esprit apparel also includes garments made from 100% recycled polyester. Esprit's recycling collections are certified with the GRS, which certifies the use of at least 30% recycled materials in clothing. (https://www. Lindex.com)

7.APPLICATION OF TEXTILES RECYCLING MATERIALS

Applications of recycled fabrics are mainly focused on construction and building industry, Currently, the materials used for thermal insulation of buildings such as mineral wool, polyurethane, fibreglass, and polystyrene are selected based on their favoured physical properties, yet they are expensive, and also known to be hazardous to human health and the environment (Oushabi et al,2015; El Wazna et al,2017). Textile waste is a better alternative than traditional thermal insulation materials regarding the environmental impact (Hadded et al,2016).

8.FABRIC TO FABRIC RECYCLING

Producing recycled fibres or separation of fibre blends was found to be the second highest studied area (21%), in which both mechanical and chemical recycling routes are employed. When recycled fibres are replaced with virgin fibres, substantial impact on reducing energy consumption and environmental pollution can be expected in the textile supply chain (Costică and Ichim 2016). The total energy saving potential ranges between 55 and 126 GJ/t, depending on the fibre type recovered (Bartl,2011). The process of recycling fabric waste into fibres involves either mechanical recycling, which is melt-extruding, or chemical recycling which is dissolving wastes in chemical solvents, and the resultant solution is re-spun into fibres (Piribauer and Bartl,2019). Textile waste represents a source of raw materials for typical application in construction, such as insulation materials for noise and temperature and fillers or reinforcements of concrete (Pichardo, P.P,2018). The conversion of fibrous carpet waste into a value-added product as soil reinforcement demonstrated that fibrous inclusions derived from carpet wastes improve the shear strength of silty sands (Ghiassian, H. et al,2008) Furthermore, textile waste is used to produce thick ropes designed for slope protection against sliding and erosion. Scraps of insulating materials produced from poor quality wool and scraps of nonwoven produced from a blend of recycled fibres were used to produce ropes. The results confirmed the usefulness of the technology for the protection of steep slopes (Anjana, E.A et al,2021)

8.CONCLUSION

This paper focused on addressing fabric waste recycling methods, issues, and challenges through a systematic literature review. The global rise in population, industrial growth, and improved living standards have caused a global fibre consumption that generates an alarming number of unwanted textiles. Textile reuse and recycling are more sustainable than incineration and landfilling, but reuse is more beneficial than recycling. For this, designing a textile product by prolonging the service life quality could promote reuse. Urgent action is needed to curtail consumption levels and establish a comprehensive textile waste management framework that integrates both economic and environmental sustainability principles. This review article offers a comprehensive exploration of textile waste in the fashion industry, highlighting the technologies used, the applications of recycled products, recovery methods, and the obstacles faced in the process.

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