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Review Article

Future of Recycling Textile Waste

Ronak Jain[1], Suman Mundkar[2], and Ashok Athalye[3]*

[1]*M. Tech Student, Institute of Chemical Technology, India*

[2]*Visiting Faculty, Institute of Chemical Technology, India*

[3]*M. Tech Professor, Institute of Chemical Technology, India*

***Corresponding author:** Ashok Athalye, M. Tech Professor, Institute of Chemical Technology, India

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Abstract

The 21st Century world is concerned about environmental pollution and its negative consequences on the environment. Therefore, the goal is to find different environmentally friendly solutions for a better present and a safe future. The textile industry generates enormous pre-and post-consumer waste, which is either incinerated or dumped in landfills. In the circular economy era, such textile waste could be recycled by a closed-loop or open-loop method to reduce environmental impact. Many firms and research institutions have prioritized this idea and are searching for more and better options. This paper reviews the reuse and recycling technologies for textile waste technologies currently used by industries. The new technology in the research phase and the potential to change how the industry will view textile waste is explored.

Keywords: Circular economy; Future prospects; Sustainability innovations; Waste recycling

Introduction

The textile sector, whose primary output is clothing and household textiles, receives the lion's share of the fibres. Their lifespan before disposal progressively decreases as these textile products transition from necessities for humans to fashion accessories. Noticeably more things are being thrown away, and the need to properly handle end-of-life textiles is growing. The amount of textile waste in terms of micro-fibres is increasing in the municipal solid waste (MSW) stream due to the fast fashion in the apparel and home furnishing segment. Usually, about 25% of textile waste is recycled or repurposed, whereas 75% is enrolled globally. The most common solution for disposing of textile waste is landfilling, which could be more sustainable. Optimized reuse and recycling technologies are required to encourage a significant divergence of textile waste from landfills. Compared to recycling, reuse is the better choice. Technologies for recycling and reusing textiles are widely accessible and have been improved over time to favour blended fabrics [1].

Objective

To summarize the current textile recycling techniques and explore new, creative recycling methods developed in the textile industry.

Recycling

Textiles become more recyclable as their complexity is decreased. To manage such textile waste, it is imperative to develop recycling technologies, enhanced collection methods, sorting automation, and to find innovative solutions. The developing topic of biochemical fibre recycling techniques constitutes a significant step towards a circular economy in the textile value chain and is the particular focus of this review. Because bio-catalysts and enzymes are highly selective, these procedures could extract a particular fibre material from post-consumer textile waste [2].

Opportunity

The environmental impact of our clothing is a factor that most people never consider. Chemicals, water, electricity, and other natural resources in substantial quantities are needed to produce textiles. According to the World Resources Institute, one cotton shirt requires 2,700 litres of water to produce. In addition to wasting money and resources when people throw away garments in the trash, it can take more than 200 years for the components to degrade in a landfill. Textiles produce greenhouse gas methane during the breakdown process, releasing hazardous chemicals and dyes into our land and groundwater. Compared to other materials, the recycling rate for textiles is now one of the lowest. But these materials, like scuffed sweatshirts, dirty pants, and even mismatched socks, can be given a fresh start as new clothes, rags, or stuffed animals. There are a lot of creative recycling ideas emerging. However, they are either not thoroughly researched, pricey, or implemented.

Current Studies

Transforming textile wastes into bio-based building blocks

Enzymatic hydrolysis has been used to upcycle textile waste made from cotton into compounds with added value. The cotton textile materials undergo direct enzymatic treatment but provide very modest yields due to their high degree of crystallinity and the presence of dyes. High enzyme loads, energy consumption, and chemical requirements are incurred to achieve high yields. Developing sustainable pre-treatment processes to upcycle cotton textile waste into glucose with low enzymatic use is needed. These treatments should be capable of dealing with the different types of colourants used for dyeing/printing textiles. This suggests that regulations for dyes could emerge in the future to attain more feasible upcycling processes for textiles [3].

Sustainable fibre-reinforced concrete

Using waste as fibre reinforcement in cementitious composites is a sustainable strategy for a circular textile economy. The recycling possibilities for textile waste, and engineering properties of concrete formed from recovered textiles are all thoroughly examined in this article. Through bridging action (a direct mechanism) and fine-tuning of pore distribution, these recycled textile waste fibres enhance strain capacity, crack control, durability, and energy absorption in concrete (an indirect effect). Compressive strength can be raised by incorporating a small number of recycled fibres into concrete [4].

Valorising textile wastes into composites

Natural fibre-reinforced composites are becoming popular due to their alluring characteristics, and properties like low weight, increased rigidity, and cost economy. Such composites are strong, lightweight, and long-lasting, becoming more widely used in markets for building, transportation, and many others. Thus, sustainability during the usage phase frequently influences choosing composites over traditional materials [5].

Electrochemical Techniques and Wastewater Treatment

The textile industry employs electrochemical methods for the treatment of wastewater as well as textile operations (such as the production of fibres, dyeing procedures, and decolourising materials). Electrochemical reduction processes are frequently utilised in sulphur and vat dyeing but can also be used to colourise effluents in specific circumstances. Nevertheless, oxidation processes provide the basis for most electrochemical treatment applications in the textile industry. Most electrochemical oxidation processes entail indirect reactions in-situ hypochlorite production or a hydroxyl radical. To achieve effluent colour removal, these electrogenerated species can bleach indigo-dyed garments and break down colourants in wastewater. Reusing the discoloured effluent can help save salt and water [6].

Phytoremediation of textile dyes and effluent

Plant-based treatment of textile dyes is relatively new and is being explored enthusiastically. Plant tissue cultures like suspension cells and hairy roots have helped achieve dye degradation. Extensive studies are being conducted on developing transgenic plants for efficacious phytodegradation of textile colourants [7].

Regenerative Textiles

Advances in materials science have produced high-value fibres from cellulose-based textiles, which can be incorporated into current textile manufacturing processes. However, there needs to be a long-term assessment of the qualities of materials after successive recycling phases [8].

Global trends of research on textile waste

A bibliometric analysis of global scientific literature on textile waste revealed the publication of 3296 articles in the last 15 years. China had the highest number of 482 publications, while India was ranked second with 421 research articles. Keywords such as pollutant, textile wastewater, treatment methods and recyclability of textile waste were identified. This study was limited in terms of the method used, as the database was limited to the Web of Science (WOS), and only English-language research articles were used [9].

Recycling of bast textile wastes into high-value-added products.

Bast fibres are widely used due to their low cost and biodegradation. Examining physical and chemical techniques for turning textile waste into valuable products such as composite reinforcements, materials for soil covering, adsorbents, supercapacitors, and nanocrystalline cellulose. Recycling of chemicals occurs more frequently than recycling materials. The recycling processes affect the final product quality; for example, chemical recycling produces more porous materials with a higher capacity for adsorption than materials made via physical recycling. Technologies for cutting-edge textile processing, as well as intelligent wearables, are discussed [10]. Some innovations are coming up that are

a. Preparation of filaments
b. Preparation of composite reinforcements
c. Preparation of catalyst
d. Preparation of sensors

Post-Consumer Textile Waste Minimization.

Overconsumption of textiles has led to their over-disposal, resulting in millions of tons of textile waste being sent to landfills annually. To reduce waste, consumers must be sensitised and encouraged to buy second-hand clothing and more durable products, that would otherwise not be worn to the end of their natural clothing life and textile products through repair. Textile products should be designed in such a way that they can be recycled after use [11].

Textile Waste for High-Density Polyethylene (HDPE) Composites

Reutilizing textile waste is an option for dealing with a global problem that stresses the urban environment. High-density polyethene (HDPE), polyethene terephthalate (PET) and rayon fibres from used clothing were used as raw materials. To create the materials under study, 30 kg of recycled clothing as the building blocks for a composite whose structural characteristics were examined. A near-infrared (NIR) analyser was used to identify the recycled clothing, and compression moulding and agglomeration technologies were used to treat the materials and reduce their size [12].

A Review of Textile Recycling Practices and Challenges

The growing textile consumption due to fast fashion has caused a rapid global increase in textile waste. Several new methods are innovative, feasible, and trending in the textile recycling market are:

a) Anaerobic digestion (AD): used to treat a biodegradable fraction of organic waste for biogas production. Textiles having over 50% cellulose content become a potential substrate for biological conversion. Pre-treatment methods enhance the biodegradation of complex organic matter in AD systems, increasing biogas quality and production.

b) Fermentation of Textile Waste for Ethanol Production: Textile waste can be used as a feedstock for ethanol production, with alkali pre-treatment and enzymatic hydrolysis enhancing yields. Cotton has the potential as an alternative feedstock for bioethanol production.

c) Composting and vermicomposting: This can improve soil fertility and provide a long-term nutrient source. Cotton gin waste is a bulking agent for pig manure composting and oyster mushroom cultivation. A new cotton waste composting technology has yielded 65% over substrate dry weight.

d) Fibre regeneration from textile waste: A closed-loop upcycling technology involves transforming the waste cotton fabrics into pulp, dissolving it using a solvent, and spinning it into fibres. Phosphoric acid pre-treatment was applied to recover polyester and glucose. Textile hydrolysis using fungal cellulase yielded a glucose recovery of 41.6% [13].

Future - From Textile Waste to Resource

This cluster aims to provide proper skills to support technological innovation and the implementation of a recycling supply chain. It provides an opportunity to use waste as secondary raw material for manufacturing environmentally friendly products in the building and eco-design sectors. It has participated in Environmental Audits, research on waste databases, life cycle assessments, supply scenarios, analysing the faults and creating prototypes for enhancing performance [14]. Figure 1 depicts MAST (Mattone in Argillan con Scarti Tessili), a clay brick from textile waste. On the left are shredded polyester threads, and on the right are clay bricks obtained with different percentages of polyester waste. Figure 2 shows the use of textile waste in experimental specimens. Wool and cashmere dust pre-mixed plaster was obtained by replacing glass fibres (Figure 3).

Figure 1: Clay Brick from Polyester Waste.

Figure 2: ReCash Plaster (Recycled Cashmere for Plaster).

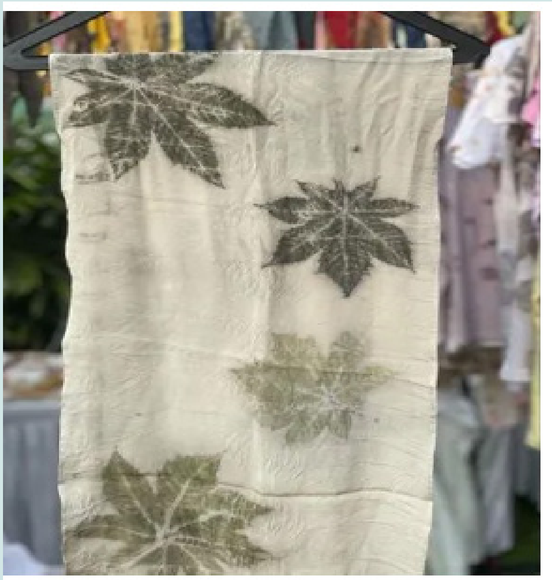

Figure 3: Flower Waste into Sustainable Clothing.

Hydrothermal Processing Technology for Recycling Blended Textiles

Circ a USA-based clean technology startup, has developed a unique hydrothermal processing technology to treat previously hard-to-recycle textiles from polyester and cotton blends. The system uses pressure, hot water, and solvents to separate polyester from cotton without damaging either. The pH of water is raised to liquefy polyester and break it into monomers of terephthalic acid (PTA) and ethylene glycol (EG). Ultimately, a liquid stream containing PTA+EG and a solid stream of only cotton is separated. PTA and EG are recombined to make virgin PET, while cotton is dissolved in a solvent that can be extruded to lyocell fibers [15].

Flower Waste into Sustainable Clothing In The Coolest Way

Labdhie Mehta, owner of the brand Sukun believes that we have to make this planet a better place for our kids and future generations she is bringing much-needed change. Sukun involves using natural dyes, including flowers from the temple waste, herbs, fallen leaves from the Jamun tree, and other good Ayurvedic stuff for the skin. Aside from printing to choosing the right fabric in her company, Mehta takes extra effort to use only environment-friendly products; she uses GOTS (Global Organic Textile Standard) certified fabric only. Labhdie Mehta's sustainable clothing products are made of naturally dyed fabrics that may fade over time. She assures that some changes may happen when the clothes meet direct sun or any metal. Ph-neutral soaps or reetha-based soaps are the suggested cleaning agents by Labdhie. Sukuun offers a variety of colours and textures to choose from, such as carrot orange, starfish orange, and purple [16].

Pastel clothing is dyed with old scraps of fabric

Pangaia, a sustainability-focused clothing brand, has collaborated with Italian textile chemical company to create dye from scraps of blue fabric collected from its factory floor. The patented process turns the recycled powder into a dye that can be sprayed, coated, printed, or dipped onto new fabric. Pangaia has previously dyed clothing with pigment made with microbes, made sunglasses from captured CO2, and created streetwear from food waste, among other innovations to reduce its environmental impact. Pangaia has previously dyed clothing with pigment made with microbes, made sunglasses from captured CO2, and created streetwear from food waste. Pangaia is experimenting with new ways to handle waste textiles in factories and from its consumers. Officina+39's technology has the advantage of working with old fabrics that cannot easily be recycled. It is non-toxic and uses less water in the dyeing process and can be filtered out of the water more efficiently than traditional dyes. Pangaia's team wants to demonstrate that it is possible to create consistent colours using various scraps collected from the factory. It also wants to be a model for brands to show how this technology can be used when everybody is responsible for up and down the supply chain [17].

Valorising cotton-polyester textile waste to pet fibre and glucose syrup

The researchers used a chemical pre-treatment before adding enzymes to fabrics treated with durable press chemicals. The polyester could be recycled, and the slurry of cotton could be used as an additive for paper or composite materials. This study evaluated the environmental implications of a novel bio-recycling method to recover polyester (PET) fibres and glucose from a 50/50 cotton/PET blend fabric waste. Environmental impacts increased as the percentage of waste PET bottle chips added decreased [18].

Summary

Proper routes of pre-and post-consumer textile wastes should be documented to spread knowledge about sustainable textiles and textile recycling. The philanthropic study of Indian populations is essential to understand their attitude towards environmentalism, recycling, and charity. Collecting facts and valuable data regarding waste generated by different production setups is critical to focus on. Experiments with pre-consumer and post-consumer wastes and their upcycling and recycling are exciting and challenging ways to help circular recycling. Awareness campaigns through books, articles, documentary films, the web, and sites can be practical tools for educating consumers and eradicating the problem of textile waste.

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