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Fabric waste recycling in the Global context

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Abstract: The waste left over from old clothing and textiles usually ends up in landfills where it is usually landfilled or burned. These disposal techniques not only harm the environment but also waste a lot of precious resources. A significant disposal issue has been brought on by the textile industry's vast volume of textile waste production. It is crucial to recycle textile waste into goods with value-added for both economic and environmental reasons. Despite the widespread desire and demand for textiles to be circular, a comprehensive concept of recycling textile waste has not yet been offered. To fill this gap, this study provides a detailed study of the amount of fabric produced globally, the amount of fabric waste thrown away globally, and fabric offcut recycling methods as well as the corresponding Challenges of Fabric Recycling.

Index Terms: Fabric offcut, recycling, Textile waste, Waste management

1. Introduction

Recycling is the conversion of waste into fresh materials and goods. The recovery of energy from waste items is usually included in this concept. How recyclable a substance is based on its ability to recapture its original properties. and fabric scraps Recycling is the technique of changing the fabric scraps that are eliminated during the creation of finished garments into a kind of raw material or a bundle that can be utilized once again. can be taken to mean. Because of rising population numbers and economic progress, there is an ever-increasing demand for textile manufacturing on a global scale. The global yearly production of textile fibers has surpassed 82 million tons in recent years, with around 40% of that amount made up of cellulosic material. As a result, the textile industry is currently dealing with significant resource and environmental issues [1]. Made from cotton and petrochemicals, it emits a considerable amount of carbon dioxide (CO_2) during production and disposal [2]. Additionally, the majority of textile waste is dumped anywhere in the world. Municipal garbage is one of the main sources of textile waste. Since the first industrial revolution, the idea and practice of recycling textile waste have been ingrained in the textile industry, and both the public and the industry need to adopt this mindset and culture [1]. This review paper's primary goal is to examine the worldwide impact of recycling textile waste.

2. Methodology

The field of this research is to examine how appropriate it is to use Fabric waste recycling in a Global context. In this research study, data were collected using quantitative and qualitative data as the study methodology for data collection. Data were collected focusing on research articles, documents, and research issues over the Internet in the aggregation of secondary data through the quantitative methodology. Here a comparative and detailed analysis of the collected data was carried out focusing on the research problem.

Fibers Types and the Global Fibers Market

Numerous different materials can be used to make fibers. Fig.1. shows the categorization of the most common fibers and mainly difference between natural and man-made fibers is first seen in the fact that natural fibers mostly consist of animal fibers. The fundamental distinction between organic and inorganic fibers is how the chemical composition of man-made fibers is classified. The organic fibers are then further classified between synthetic fibers made from petroleum and natural polymers, primarily cellulose [3].

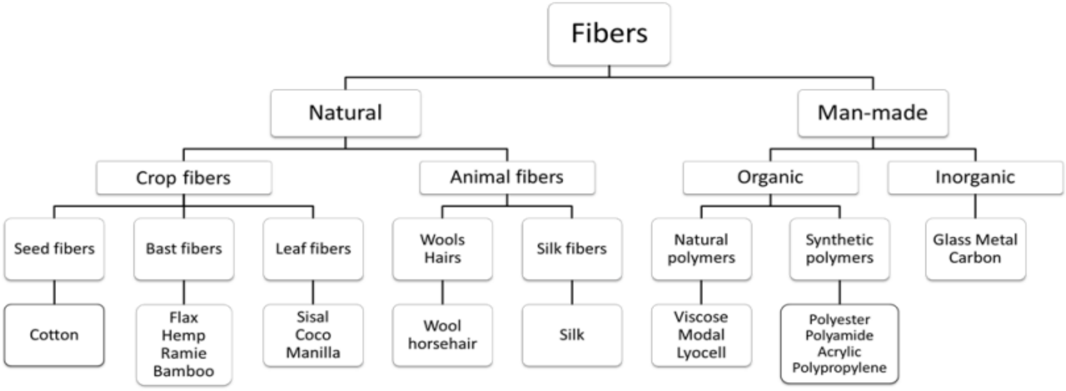

Fig.1. Categorization of the most common fibers

Although there are numerous paths that fibres might take to become a fabric, they are normally spun into yarns and then knitted or stitched into fabrics. A plant in the genus Gossypium produces cotton as a fiber that is extracted from its seed. Cellulose is the principal constituent of fibre, however, depending on the development conditions, the percentage of it in the cotton plant varies from 90 to 95 percent. Fibers made of linear macromolecules are polyester (fibers made from petroleum). To be categorized as polyester fiber, a fiber must include at least 85% of the mass in the form of an ester of terephthalic acid and a diol. This is accomplished by the polymerization process [4]. In 2011, a rise in production volume in the world textile industry (all textile sectors) by 6.4 percent was stated in The Fiber Year (2012) meaning production of 85.9 million.t. Out of these, 33.2 million.t were made up of natural fibers and 52.7 million t of man-made fibers resulting in an increase of 7.1 and 6.0 percent respectively). Considering consumption instead, the volume reached 82 million t in 2012[3]. States that global consumption has increased steady steadily 9.4 million.t in 1950 to 70.5 million t in 2009 due to 4 population growth and improved living standards [3]. Cotton is, according to the same source, the second most important fibre as it amounted to 34% of all fibre types the same year. Fig.2. shows the total global fibre production [4].

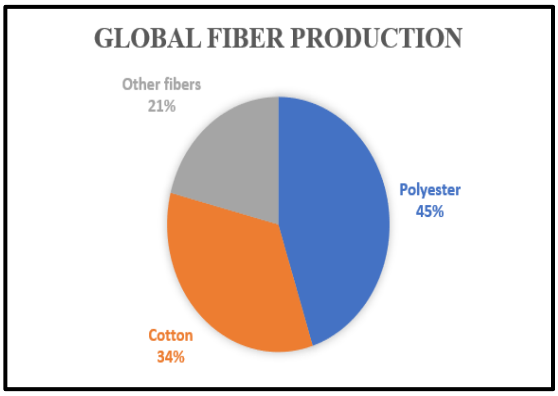

Fig.2. Total global fiber production in 2008[4]

Distribution of fabric recycling by fiber type

Although polyester fiber output is rising globally, as was already said, cotton and cotton/polyester mixes are the most often used textile waste for recycling applications. It has been discovered that fiber blends other than cotton or polyester are less likely to be recycled. Unblended cotton waste, which accounts for 47% of recycled textile waste as indicated in Fig.3. has attracted substantial attention in both chemical and mechanical recycling processes. The most popular natural fiber in the textile business, cotton must be recovered from waste materials to reduce environmental issues. Research has also shown interest in the recycling of cotton/polyester blended or blended textile waste, which accounts for 27% of recycled textile waste. Other types of textile waste are observed to be less frequently recycled [5].

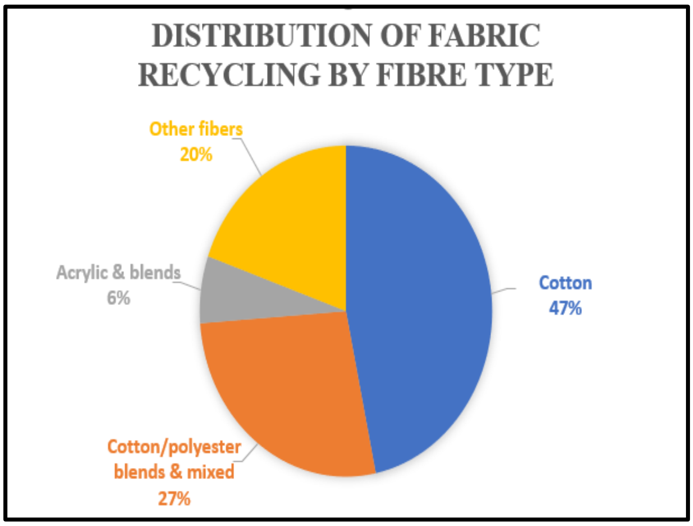

Fig.3. Distribution of fabric recycling by fiber type

3. Methods of Fabric Recycling

Textile recycling can broadly be divided into main two categories, it is based on the intended end product.

- Open-loopop recycling
- Closed loop recycling

Open-loop recycling - The properties of the recycled material are different from the original material and, therefore, the recycled material is used for a different product or purpose than the original. That is, the open-loop recycling process transforms the waste into a new type of material that can be used as an input to another production process [6].

Closed loop recycling - Recycled materials can replace original virgin materials. This means that the closed loop recycling process converts the waste back into a product similar to the original product. Therefore, closed-loop recycling is important to reduce the environmental impact created by the textile industry, and it can be achieved by converting a worn-out garment/fabric into its original fiber form after recycling, which is used to create a similar product [6].

Fabric recycling can be mainly classified into three methods which are

- Mechanical recycling methods
- Chemical recycling methods
- Biochemical recycling methods

- Thermal recycling methods

However, thermal recovery is the least preferred option in terms of resource recovery.

With 43% of the research, mechanical recycling is the most investigated type. According to the study, the demand for chemical recycling is 38% higher than the demand for mechanical recycling. This is mostly because recycled polyester fibers or lyocell must be made from textiles like cotton and thermoplastics. 14% of recycling is biochemical, which indicates a far lesser demand than recycling that is mechanical or chemical. The least recommended technique has been determined to be thermal recycling. Textile recycling can also benefit from an integrated approach to mechanical, chemical, and thermal processes. For instance, used clothing can either be mechanically recycled after chemical treatment or chemically treated after mechanical recycling. Recycling different complex fiber mixes can be accomplished by combining two or more techniques. Cotton and cotton/polyester mixes are the most often used textile waste for recycling applications, according to Fig.4. Other than cotton or polyester, mixtures of fiber are far less likely to be recycled [7]. As illustrated in Fig. 4. unbleached cotton waste garnered considerable interest in both chemical and mechanical recycling pathways, making up 50% of recycled textile waste. To allay environmental worries, the textile sector now places more emphasis on cotton than polyester made from petroleum. Research has also shown interest in the recycling of cotton/polyester blends or blended textile waste, which accounts for 29% of recycled textile waste. Other kinds of fabric waste recycling receive a little too little attention. These techniques for fabric recycling are covered in depth in the section that follows [5].

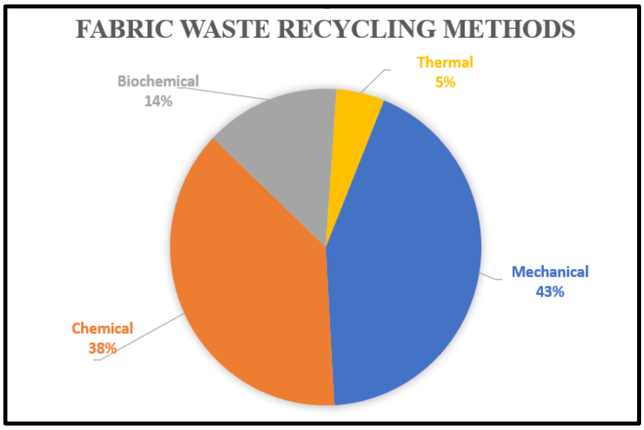

Fig.4. Fabric waste recycling by methods

3.1 Mechanical recycling methods

The mechanical recycling method can be divided into two ways depending on the recycling mechanism applied and Fig.5 shows the Mechanical recycling process. The first route is the Solvent-extrusion process, where the material is shredded, crushed, twisted, then melted, and re-extruded to obtain the fibers to be re-spun into yarn or to produce woven boards. Synthetic fabrics such as polyester or nylon can be cut and converted back into fibers by direct extrusion into fibers or by converting the forgings into flakes or chips and then melting the extrusions into fibers. The second route involves cutting, shredding, and carding to open the fibers used to produce various building and industrial applications [8].

Fig.5. Mechanical recycling

3.2 Chemical recycling methods

On two acres, chemical fabric recycling can be done Fig.6. shows the chemical recycling process. The first pathway breaks down the waste into its component monomers through depolymerization and polymerization. Plastic polymers, like polyester, can be broken down into monomers or oligomers during the depolymerization process and then reconverted into new fibres or materials[9].

The second step, known as the dissolution pathway, involves the separation, filtration, and regeneration of fibers. Ionic compounds are employed as solvents in the dissolving process, which involves using cellulose fibers like cotton or viscose to dissolve the cellulose. By severing intramolecular hydrogen bonds, solvents speed up the process of cellulose dissolution. By coagulating, the cellulose that has been dissolved in an ionic liquid can be transformed into a variety of materials, including synthetic cellulose fibers, films, aerogels, and hydrogels. Regenerated cellulose can be created by dissolving cellulose molecules with chemicals. The same goes for polyester, which can be dissolved using substances like dimethyl isophthalate, dimethyl terephthalate, or methyl-p-toluate before being recovered and spun back into the polyester. Instead of being made up of only one fiber, textile items are typically made of fiber blends. Therefore, mixture separation using solvents has also been investigated by many researchers. For the separation of cotton/polyester blends, 1-allyl-3-methylimidazolium chloride can be used as the ionic liquid, which selectively dissolves the cotton and recovers the polyester in a high yield [5].

Fig.6. Chemical recycling process

3.3 Bio-chemical recycling methods

The environmentally beneficial biochemical method of recycling textiles uses enzymes to disassemble polymers into monomers and Fig.7. shows the Bio-chemical recycling process. A pretreatment process in an acid or alkali that aids in dismantling the fiber's macrostructure is typically the first step in biochemical recycling.

The most popular pretreatment method for cellulose-based fibers is acid pretreatment, which can hydrolyze the amorphous portion of the fiber and expose the crystalline portion to enzymatic destruction. By causing the cellulose molecules to swell, alkaline pretreatment can be utilized to break the inter- and intra-chain links, allowing more room for enzymatic treatment. For the pretreatment of alkalis, sodium hydroxide, potassium hydroxide, and calcium hydroxide are the most often utilized compounds. The cellulose chains in the textile waste can be broken down into smaller molecules by cellulose enzymes, creating synthetic waste[10].

However, synthetic blended or colored cotton requires efficient pretreatment since it does not respond well during enzymatic hydrolysis. The ester connections of the polymer chain can be broken and converted into monomers using biochemical recycling techniques, which can also hydrolyze synthetic materials like polyester in addition to cellulose-based polymers. These monomers can be utilized again to make new polymers or in a variety of different ways. However, because big protein molecules cannot pass through the polyester material during the hydrolysis process, hydrolysis only takes place on the surface material, which reduces the method's economic viability.

Fig.6. Bio-chemical recycling

3.4 Thermal recycling methods

Instead of recovering fabric offcuts, the heat recovery process turns waste into electricity [11]. Textile waste has a significant energy content, making it a potential source of energy. The three primary heat recycling techniques are combustion, pyrolysis gasification, and incineration. To generate heat, fuel and oxidizer engage in a series of exothermic chemical events known as combustion. In pyrolysis, organic matter thermally decomposes without the presence of oxygen [12].

4. Applications of Recycled Fabrics

The following Table.1. shows the commonly used types of fabric offcuts and their uses as well as the recycling method used to produce them [5].

Table.1. Recycling of fabric waste for various applications

Recycling Method	Possible fabric material	Output
Mechanical	Cotton	Thermal and sound insulation
		Microcrystalline cellulose reinforced composite
		Waste textile reinforced composites
		Cotton yarns
		Automotive components
	Cotton/ polyester blend	Composites
	Cotton/ polyester mix	Automotive textiles
	Cotton (knitted)	Recycled fibers
	Cotton (denim)	Fiber reinforced composites
		Composites for automotive industry
		Fiber reinforced concrete
		Sound insulation panels for buildings
		Fiber reinforced composites
Chemical	Cotton	Cotton fibers
		Microcrystalline cellulose
		Microcrystalline cellulose
		Conductive electrode
		Regenerated cellulose fibers for the textile industry
		Hydrogel as a heavy metal adsorbent
		Cellulose Easters
	Cotton (denim)	Cellulose aerogel
	Cotton (denim/ easy care finished cotton)	Recycled cotton
	Cotton, cotton/polyester blends	Bacterial cellulose
	Cotton/Polyester blend	Electrochemical applications
	Cotton/nylon blend	Regenerated cellulose films and nylon 6 fibers
Biochemical	Cotton/polyester blend	Ethanol and polyester
	Cotton/polyester blends	Glucose and polyester

5. Challenges of Fabric Recycling

5.1 Material complexity

Fabric product variants differ from one product to another due to material complexity. dependable textiles. Their varied mix is a significant impediment to recycling. For instance, there is a lot of variability in the fiber blends and product structures of various products. As a result, recycling technology development is more challenging than it is for other manufacturing sectors that use homogeneous materials. In addition, most textiles and clothing are made from many materials. Once blended, some fiber mixes are challenging to separate. Although attempts have been made to separate mixes of different materials using chemical recycling methods, recovery is still only possible for mixtures based on cellulose fibre [13].

5.2 Management of post-industrial waste

Control of post-industrial waste, including surplus fabric, roll ends and cutting waste. Despite being in brand-new condition, the fabric cannot be used because of cutting waste and small-roll leftovers. The recovery of fiber from such mixed wastes is hampered by the inclusion of fiber blends, textile dyes, other organic components, and a heterogeneous mixture. Additionally, a lot of factories have agreements in place with the relevant companies for brand protection, making burning the only practical solution for dealing with a mixture of cut waste and extra fabric [14].

5.3 Quality Issues

Quality Problems Quality is a crucial component of any product. There is no widely established quality management process for waste sorting and segregation, hence the decision to recycle textile waste is mostly based on subjective assessments of waste quality management. The sorters' experience, the target market, and the garbage collection's quality levels all play a role in the evaluation of quality. The fibers' physical attributes are diminished during the recycling process [15].

Plastic fibers shorten and deteriorate during each recycling procedure. After being recycled 7-9 times for plastic fibers and 4-6 times for cellulose fibers, respectively, they are no longer eligible for recycling. Cotton fibers that have been mechanically ginned are often shorter in length, and the final product is of lower quality. The waste fabric, its structure, and the shredding parameters all affect the quality of recycled yarn. Therefore, to enhance the quality of mechanically recycled cotton yarn, it is required to methodically segregate the trash and adjust the shredding settings[16],[15].

5.4 Color and Chemical problem

Chemicals used in textile processing include many dyes, mordants, softening agents, finishing agents, and coating agents. The fabric's ability to be recycled is severely constrained by the presence of those chemicals. Although PET bottles can be recycled technologically, polyester fabrics cannot be recycled using the same process because of the presence of colours. For instance, the degree of polymerization during the melting process might be decreased if the dispersion dye is not removed from the polyester fabric before recycling [17]. The decomposition process becomes more challenging as a result of many chemicals used during colouring and finishing. In addition, there is a growing market for utilitarian and high-performance textiles. Many chemicals are applied as coatings to add special functionality to fabrics such as water repellence and hydrophobicity. These special finishes and coatings make the recycling process more difficult [9].

6. Conclusion

In this study about the recycling of cotton-based textiles, it was determined that the majority of the production of polyester-rich fabrics in the world and the majority of them are mechanical. This was by the findings of the qualitative and quantitative data of this research, according to the data mentioned in 2009. The usage of recycling techniques and chemical recycling techniques was validated. Additionally, the use of recycling fabric offcuts as well as the challenges it presents are discussed in this study's executive summary. Finally, with this knowledge, individuals can learn about the recycling of fabric waste on a global scale.

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