Transforming Textile Waste into Sustainable Yarn

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Abstract

At present, the textile industry's extensive consumption and subsequent waste production on a global scale are precipitating adverse environmental consequences, highlighting the imperative need for effective textile waste management. To address this issue, it is essential to develop a process for producing recycled yarn from textile waste. This research endeavors to mitigate textile waste and promote sustainability. The resulting yarn qualities, including count strength product (CSP), elongation percentage, tenacity etc. exhibit a linear decrease with increasing amounts of waste added to the virgin cotton. Conversely, characteristics such as thick, thin places, hairiness etc. show an opposite trend, increasing with greater incorporation of waste. In today's world, there is a widespread global interest in sustainability. Hence, this paper offers a comprehensive overview to convert textile waste into recycled fibers, aiming to create sustainable yarns that conserve resources and tackle environmental issues, ultimately contributing to the establishment of a eco-friendly society.

Keywords:*Textile waste, Recycling, Recycled fibre, Sustainability, Eco friendly.*

1.Introduction

This is the time to consider textile waste management. Textile waste poses a significant threat to environmental health. This waste includes industrial or pre-consumer waste produced during the manufacturing process, as well as post-consumer waste, which consists of textiles discarded after their useful lifespan. Effective management of apparel waste is crucial, as modern clothing is designed for short-term use and quick disposal. Unfortunately, only 20% of clothing waste is recycled or reused, while the remaining 80% ends up in landfills or is incinerated. This results in a substantial loss of raw materials and energy, and has a detrimental impact on the environment [1]. The World Economic Forum reports that 85% of used clothing ends up in landfills each year, where it is either incinerated or contributes to waste accumulation. Furthermore, 12% of worn clothing is repurposed as cleaning cloths for household items like kitchenware and furniture, while only 1% is upcycled into new garments [2].The process of recycling entails turning waste materials into new goods. Reusing and repurposing clothes scraps or any other fibrous textile material is referred to as textile recycling. Both consumer and industrial discarded textile goods are utilized as textile waste for recovery. It is evident that recycling, which has developed into a key aspect of sustainability, has been recognized for its importance since ancient times [3]. Rising costs in textile manufacturing, including those for raw materials waste management etc. are putting considerable strain on businesses globally. The textile industry contributes approximately 10% of global carbon emissions, making it the fifth largest emitter. To combat this, optimizing natural resource use by reducing raw material consumption through the reuse of textile waste is essential. This technique provides a useful way to handle waste textiles [4].

Sustainable textiles are produced through environmentally friendly processes, ensuring that all materials, inputs, and outputs are safe and healthy for people and the environment throughout the product's life cycle. Manufacturing and processing sustainable textiles from renewable or recycled sources not only mitigate negative environmental impacts but also provide fair wages and proper working conditions for millions of workers. The use of natural resources has surged in recent years, and the chemicals used in the textile industry have exacerbated water pollution, contributing to water scarcity. Additionally, textiles consume significant amounts of fossil fuels during wet treatments. These fuels, rich in carbon, react with oxygen to form carbon dioxide, thereby accelerating global warming. The apparel industry must address these environmental hazards and enhance process efficiency [5]. Recycling is the process of repurposing garbage to create new products. Each of us plays a crucial role in protecting the environment, making recycling and reusing waste essential for sustainability, as they reduce negative environmental impacts. Almost everything around us can be recycled and utilized efficiently. Sustainable recycling is a responsible approach to solid waste management, vital for a sustainable society. While the environment may suffer from current disposal practices, sustainable recycling contributes to resource conservation and lessens environmental harm. Moreover, recycling reduces pollution and

safeguards the natural ecosystem [6] . Pre- and post-consumer recycling are the two main categories of recycling that the textile industry primarily concentrates on. The first step involves sorting the waste materials sourced from various places. Textile waste is manually separated based on the fabric, fibers, and quality or condition. Based on the type of fabric, waste is processed into fibers through mechanical methods like cutting and shredding. After that, these fibers are made into garments or spun into yarn.Textile recycling plays a crucial role in generating new resources, creating employment opportunities, and fostering charitable initiatives. Moreover, recycling greatly reduces carbon dioxide emissions .It is essential for textile industries globally to focus on recycling the waste they produce. Implementing a well-structured recycling system can offer significant environmental advantages while also being cost-effective [7]. Several studies have looked at waste's effects on yarn quality from different perspectives. The physical and mechanical qualities of yarn are greatly influenced by waste from various parts of the garment industry, according to the results of multiple research. The goal of G.M. Faysal et al. [2] was to turn clothing waste into rotor yarn. To determine whether the yarn was feasible, they looked at its tensile and physical characteristics. They also assessed the impact on yarn performance of varying virgin cotton to leftover waste composite yarn ratios. Jamshaid et al. [1] demonstrated that hard waste from spinning fragments can be transformed into open-end (OE) yarn. Their findings revealed that yarn waste exhibited superior homogeneity, floating fiber properties, and fiber length consistency compared to rag waste. Awgichew et al. [8] explored the impact of incorporating recycled fibers into OE-rotor yarns, comparing the performance of yarn made from 100% virgin cotton with blends containing 25%, 50%, and 75% recycled fibers. They discovered that the yarns manufactured completely of virgin cotton had a lower tensile strength than the yarns combined with recycled fiber. Mehmet et al. conducted a study [9] evaluating the properties of yarns and fabrics made from virgin and recycled polyester and cotton fibers. They combined fibers from virgin cotton, recycled cotton, virgin polyester, and recycled polyester to make open-end rotor yarns. After that, single jersey garments were knitted using these yarns. Physical properties of the yarns and fabrics that were evaluated and statistically analyzed included tensile strength, unevenness, yarn flaws, burst strength, pilling, and the coefficient of kinetic friction.The importance of waste generated in a cotton textile mill was emphasized by Mohamed Taher Halimi et al. [10], who noted that it affects mill profitability and operational expenses. The cleaning behavior of each waste in the spinning preparation process is predicted by evaluating the trash content and preliminary processing. The recovered fibers' quality is contrasted with that of other virgin cotton. The study investigates the impact of cotton waste on rotor yarn quality in order to assess these fibers. The created waste contains roughly 50% excellent fiber, according to the results. This secondary raw material exhibited excellent cleanability and characteristics, making it suitable for blending in proportions of 15 to 25% with minimal impact on rotor yarn quality. Ahmed Jalal Uddin et al. [11] present a sustainable method for producing melange yarn from recycled fibers sourced from pre-consumer cotton/viscose melange fabric waste. The shredding process yields short, lumpy recycled fibers, requiring them to be blended with virgin fibers that act as carriers during spinning. In traditional ring spinning, the poor cohesion of shorter recycled fibers hinders the attainment of optimal yarn quality. Hafeezullah et al. [12] Conducted a study to evaluate the properties of yarns produced from recycled fiber blends, aiming to optimize the blending proportions. and to determine their suitability for denim fabric production. They investigated the properties of recycled fiber and virgin cotton spun on open-end with a count of 4.5 Ne, using fiber proportions of 20/80, 25/75, 30/70, 35/65, 40/60, 45/55, and 50/50. The results were analyzed using Design-Expert software and a central composite design to optimize the proportions. Ahmed et al. [13] explored a sustainable method for producing Siro grindle yarn with a vibrant grindle effect, focusing on maximizing the use of recycled cotton fibers obtained from pre-consumer fabric waste. The aim of this study was to produce rotor yarn from post-consumer textile waste. To assess its feasibility, various yarn qualities were examined, including total quality index (TQI), elongation percentage, tenacity, thick and thin places, neps, hairiness (H), imperfection index (IPI), and count strength product (CSP). Additionally, the performance of yarn made from different ratios of virgin cotton and post-consumer waste was evaluated. The overarching goal of this research is to recycle and reuse textile waste to create sustainable yarns that conserve resources and address environmental challenges, thereby contributing to the development of a sustainable and eco-friendly society.

2. Methodology

Post-consumer waste refers to household items or garments that the owner no longer needs and has chosen to dispose of. This includes out-of-fashion or damaged clothing. Globally, a large volume of textile waste is

produced, with 50% being recyclable and the other 50% being reused. The textile recycling industry consists of key players such as NGOs, profit-driven retailers, and solid waste managers.
Rag graders are responsible for the final stage of post-consumer waste management. Numerous companies are emerging in this industry, focusing on waste sorting. These businesses gather, classify, refine, and export goods derived from post-consumer garbage to different markets [14] .



Fig 1: Steps for Recycling Fabric Waste

Fabric waste collected for recycling was processed into recycled fiber using a Garnet shredding machine. Figure 1 shows the process of recycle fibre extraction from waste fabric. The properties of the recycled fiber were subsequently analyzed, as outlined in Table 1. Virgin cotton fiber and recycled cotton fiber were obtained from the factory, and their characteristics were evaluated using a Uster High-Volume Instrument, Switzerland. Measurements were taken for fiber length, fineness, strength, maturity, elongation, tenacity etc. Also Table 2 indicates the virgin cotton fiber properties and Table 3 indicates the fiber mixing ratio percentage.

Table 1. Recycled fiber properties.

Properties	Value
Fibre strength(CN/tex)	27.6
Fibre Fineness(mic/inch)	3.8
Fibre tenacity(CN/tex)	22.1
Maturity(%)	82
Fibre elongation(%)	8.0
Short fibre (%)	9.7
UHML(mm)	24.3

Table 2. Virgin cotton fiber properties.

Properties	Value
Fibre strength(CN/tex)	29.8
Fibre Fineness(mic/inch)	3.4
Fibre tenacity(CN/tex)	26.6
Maturity(%)	85
Fibre elongation(%)	8.3
Short fibre (%)	8.1
UHML(mm)	29

Table 3. Fibre mixing ratio

Virgin cotton%	Recycle fibre%
30	70
15.5	84.5
20	80
40	60
65.5	34.5
83.5	16.5

2.1 The process flowchart of yarn manufacturing:

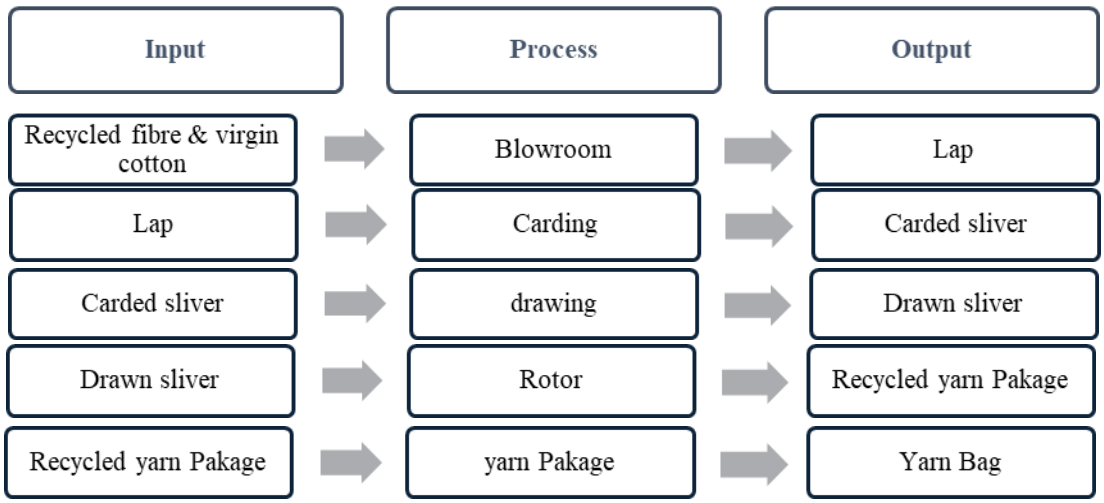


Fig. 2. Process flowchart of yarn manufacturing

Initially, recycled fibers and virgin cotton fibers were gathered together. The required amounts of recycled and virgin cotton fibers were then measured according to the desired blend ratio. These fibers were thoroughly mixed by hand and with a willow machine. Once blending and mixing were completed, the materials were processed through a blow room line, where the cotton fibers were opened, cleaned, and converted into a lap. Following the blow room, the next step was carding, where the materials were fed through a chute into a carding machine, which transformed them into a uniform strand of fiber known as sliver. The sliver was then drawn through the finisher draw frame, producing drawn sliver. This step equalized short- and medium-term variations in the carded sliver, while the curled, hooked, and crimped fibers were straightened. At this stage, a close blend

of virgin cotton and recycled fibers was achieved. Table 4 indicates the equipment that is required to produce virgin cotton and recycled fiber yarn.The goal of this process was to create yarns from textile waste and virgin cotton blends with a lower twist in the rotor frame, suitable for garment production. Finally, the finisher draw frame slivers were fed into the rotor spinning process, where the drawn sliver was transformed into recycled yarn packages. Here figure 2 shows the overall process flowchart of yarn manufacturing.

Table 4. Equipment specifications for producing recycled fibre /virgin cotton yarns

Process	Machine/model	Origin/Country	Delivery	Speed
Blowroom	Rieter(Uniflock A11,Uniclean B12,Unimix B70, Uniflex B60)	Switzerland	Card mat	1100 kg/hr
Carding	Rieter C60	Switzerland	Card sliver	65 kg/hr
Breaker Drawframe	Rieter SBD-40	Switzerland	Drawn sliver	650 m/min
Finisher Drawframe	Rieter RSBD-40	Switzerland	Drawn sliver	650 m/min
Rotor	Rieter R 923	Germany	Yarn Count: 24 Ne (TM 3.90)	75000 rpm
Autocone	Muratec (21-C)	Switzerland		

3. Results and discussion

3.1 Physical properties of yarn

In this study, the physical properties of yarn produced from varying proportions of recycle fibers and virgin cotton were measured. The key properties include Coefficient of Variation of mass (CVm%), thin places, thick places, neps, hairiness, and the imperfection index (IPI). These factors directly affect the quality and appearance of yarn and its suitability for various textile applications. Table 5 indicates the physical properties of yarn samples. In our laboratory, we use the Uster® Tester 5 to measure all essential yarn characteristics.

Table 5: Physical properties of yarn samples

Sample Type	CVm%	Thin (-50%)/km	Thick (+50%)/km	Neps (+280%)/km	Hairiness (H)	IPI
N1	13.91	3	36	6.33	7.8	45.33
N2	14.02	4	37.33	7	7.9	48.33
N3	14.27	4	37.33	8	8.1	48.67
N4	14.62	5.33	38.67	9.33	8.3	53
N5	14.68	5.33	40.33	11.33	8.4	56
N6	15.34	6.33	46	14	8.9	66

Here are the fig.3 graphs showing the correlation between recycle fiber percentage and (1) Hairiness and (2) Yarn Imperfection Index (IPI):

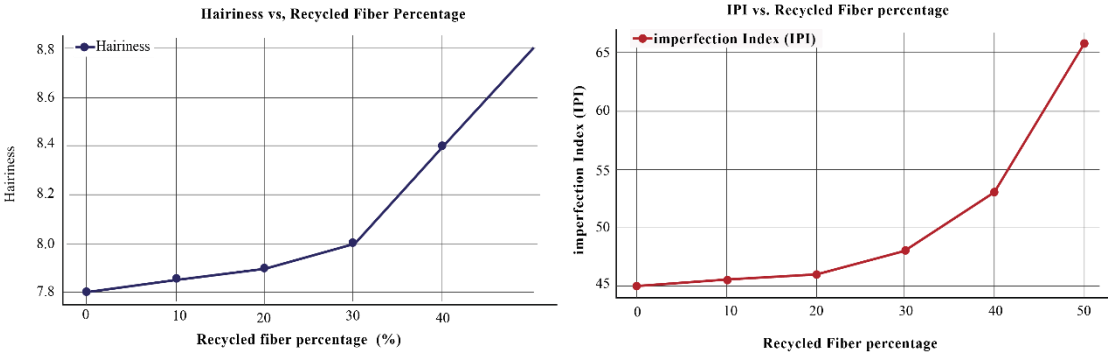


Fig.3: Hairiness and yarn imperfection index (IPI) correlation values depending on the recycle fiber percentage

Hairiness vs. recycle fiber percentage:

As the proportion of recycle fibre increases, the hairiness of the yarn gradually rises, indicating more protruding fibers.

Imperfection index (ipi) vs. recycle fiber percentage:

Similarly, the IPI increases as the percentage of recycle fibers grows, demonstrating a higher occurrence of

irregularities such as thin places, thick places, and neps. Here fig 3 indicates the hairiness and yarn imperfection index (IPI) correlation values depending on the recycle fiber percentage.

3.2 Tensile characteristics of yarn

The created yarn samples (marked as N1–N6) were made by varying the ratios at which virgin cotton and recycled fiber were blended. The tensile characteristics of the yarn samples are shown in Table 6. The tensile properties of the yarn samples are presented in Table 6. The Universal Testing Machine (UTM) was used across various textile factories to assess the tensile characteristics of the yarn. Following analysis, the tensile properties—tenacity, elongation, count strength product (CSP), and Total Quality Index (TQI)—are outlined below:

Table 6: Tensile properties of yarn samples

Sample Type	Tenacity (cN/tex)	Breaking Elongation (%)	CSP	TQI
N1	9.56	6.25	1710	3.85
N2	9.1	5.95	1655	3.63
N3	8.65	5.6	1590	3.38
N4	7.98	5.2	1487	2.94
N5	7.3	4.85	1380	2.45
N6	6.5	4.5	1265	2.05

The yarns showed a progressive decrease in tenacity, elongation, CSP, and TQI as the proportion of recycle fibers increased. Notably, the tenacity dropped significantly from 9.56 cN/tex in N1 to 6.50 cN/tex in N6, reflecting the influence of the increasing proportion of short fibers, which are more prone to slippage during tensile testing.

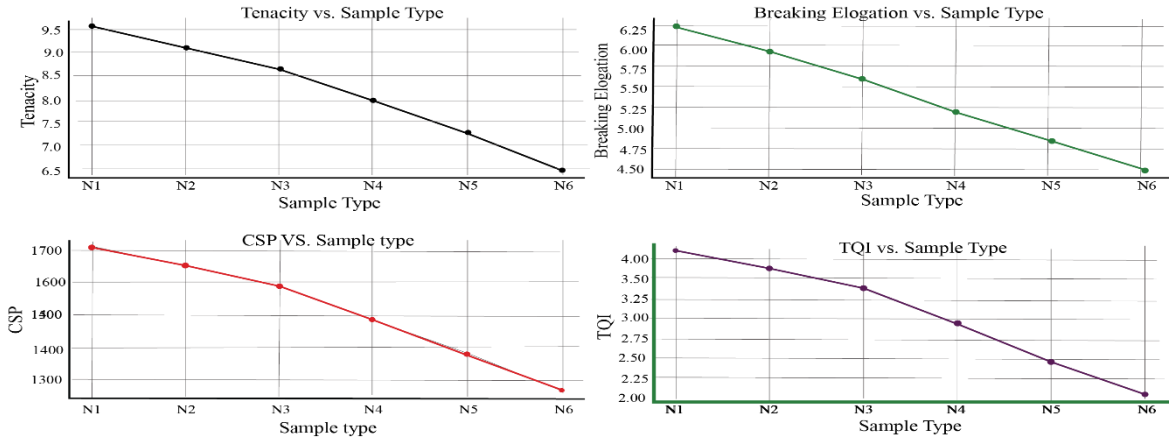


Fig.4: Tenacity, CSP, TQI, breaking elongation correlation values depending on the recycle fiber percentage.

The yarn sample representation graphs (N1–N6). Tensile qualities, including Tenacity, Breaking Elongation, Count Strength Product (CSP), and Total Quality Index (TQI), are correlated with sample type as indicated by each graph. Here fig 4 indicates the Tenacity, CSP, TQI, breaking elongation correlation values depending on the recycle fiber percentage.

3.3 Discussion

The findings of this study reveal that increasing the percentage of recycle fibers in yarn production leads to a noticeable decline in both physical and tensile properties. While blending recycle fibers with virgin cotton may provide cost-saving and sustainability benefits, it results in higher imperfections, reduced strength, and lower overall yarn quality. For industries considering such blends, a balance must be struck between sustainability goals and the desired quality attributes of the final product. Further research could explore ways to optimize the blend ratio or treat leftover fibers to minimize the negative impact on yarn properties.

4. Conclusion

There is an urgent need to reduce the textile waste generated by the industry. Recycling not only minimizes waste and pollution but also promotes sustainable resource use. By conserving valuable natural resources, recycling decreases the demand for virgin materials and reduces energy consumption. Additionally, the

recycling industry creates jobs, raises environmental awareness, encourages a culture of sustainability, and generates revenue, contributing to economic growth. Although recycled cotton fibers from textile waste contain high amounts of short fibers and neps, blending them with virgin cotton has successfully produced medium count yarns. Compared to 100% virgin cotton yarn, blended yarns with recycled fibers show higher CVm and imperfections, along with lower strength and elongation as the proportion of recycled fiber increases. While using recycled fibers may slightly reduce yarn strength and, consequently, the lifespan of garments, this is outweighed by the benefits of using sustainable raw materials in yarn production.

Today's consumers are increasingly mindful of purchasing sustainably and ethically produced products. Beyond the apparel industry, sectors such as furniture, automotive, construction, and carpets also seek sustainable, eco-friendly yarns containing recycled fibers. With numerous potential applications for recycled fibers, the industry must adopt innovative techniques, advanced machinery, industrial production practices, and greater entrepreneurial investment to meet growing demand. Future research scope will prioritize the development of advanced technologies for fiber separation, purification, and regeneration to enhance the quality and uniformity of recycled yarns, ultimately supporting more sustainable textile production.

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