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Utilizing Circulose fibers in the production of denim fabrics in the context of textile waste management: A case study in DNM textile factory

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Abstract

The textile industry has a massive environmental impact, not only because it consumes enormous amounts of raw materials and effluents, but also because each piece of textile produced eventually adds to the vast number of waste textiles. This research aims to study how textile waste can be recycled and reused in the textile industry. This research was conducted through a field study of DNM textile for spinning, weaving and dyeing factory in new Damietta, Egypt, where yarns produced from recycled Circulose fibers blended with Cotton fibers and used as weft yarns to produce denim fabrics with various structure weaves (3/1 Twill weave – Satin 4 weave – 2/2 Twill weave and 2/2 Matt weave) and compare them with samples made with same weave structures with traditional blended Tencel/Cotton yarns as wefts in fiber cost and mechanical properties of produced fabrics. The results showed that the cost of Circulose fibers is lower than that of Tencel fibers, with the percentage of 21.88%, and blended Circulose/Cotton achieved a quality coefficient convergent with Tencel/Cotton in mechanical properties, with a difference percentage of 1.21%.

Keywords

Sustainability, Textile waste management, Recycling, Circulose® fibers, DNM.

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1- Introduction:

In the 21st century, environmentalists have been increasingly interested in sustainable waste management. (1) High energy use, climate change, and a shortage of natural resources necessitate more sustainable human conduct to preserve modern society's survival and the future of subsequent generations. (2) The world is confronting an increasing textile waste dilemma as a result of global population expansion, improved living standards, and a reduction in textile product life cycles. (3)

The textile industry has the fourth highest environmental impact, behind housing, transportation, and food. Global fiber output has nearly quadrupled over the last two decades, rising from 58 million tons in 2000 to 109 million tons in 2020. Furthermore, these figures are predicted to rise by 34% by 2030 if current industrial practices continue. (4) As a result, the environmental management system is one of the criteria for green textile strategies. (5)

Research Problem:

The research problem is limited to the following questions**:**

1- What is the importance of textile recycling in disposing of textile waste?
2- How can we protect the environment by recycling textile waste?
3- How can textile waste be recycled and reused as fibers, such as Circulose fibers, in producing denim fabrics with a lower cost and appropriate quality?
4- What is the difference between recycled Circulose fibers and Tencel fibers used in the DNM factory in terms of cost and mechanical properties when used in the production of denim fabrics?

Research importance:

1- Raising environmental awareness of the importance of recycling industrial waste, especially in the textile industry, to preserve the environment.
2- Reducing the consumption of resources required to manufacture textile products and replacing them with resources extracted from textile waste.
3- Utilizing Circulose fiber from textile waste to produce denim fabrics at a low cost and appropriate quality for traditional fabrics from Tencel fibers used in the DNM factory.

Research objective:

This study aims to:

1- A case study in DNM textile for spinning, weaving, and dyeing factory in New Damietta, Egypt, on the production of denim fabrics using recycled Circulose fibers from textile waste.

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2- Study the mechanical properties of fabrics produced from recycled Circulose fibers and compare them with traditional fabrics from Tencel fibers with the same weave structures.

Research methodology:

This research follows the experimental method and the analytical method.

2- Textile waste management:

Textile recycling is an important component of decreasing the large waste problem caused by the fashion and textile industries. In this context, textile waste is divided into three categories: pre-consumer, post-consumer, and industrial waste, as seen in fig. (1). (3) Pre-consumer textile waste encompasses waste generated during the processing of fibers, yarn, fabric, and nonwovens, as well as apparel production. Pre-consumer textile waste is commonly regarded as "clean waste" because it is generated during the textile manufacturing process. (6) Post-consumer waste may comprise waste from second-hand textiles dumped by consumers in the form of apparel and other goods like curtains. (4) Industrial waste is made up of leftover fibers or cutting scraps from industrial processes, including spinning, weaving, and textile manufacturing. (7)

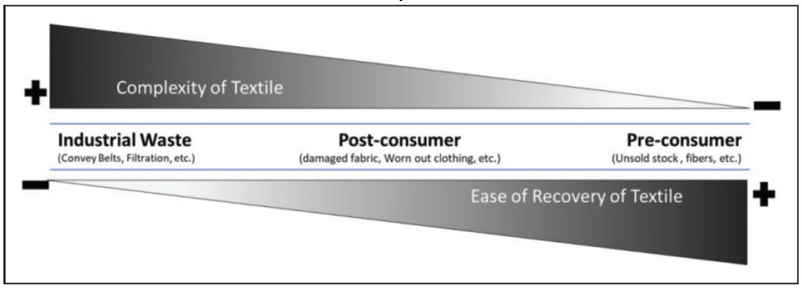


Fig. (1): Various categories of textile waste and the difficulty of recycling them

2-1- Types of textile recycling:

There are two types of textile recycling technologies: mechanical recycling and chemical recycling. Mechanical recycling is the conversion of textile waste into secondary raw material while preserving the polymer chemical structure of the fibers. Chemical recycling of textile waste, on the other hand, appears to be a promising alternative since it can overcome some of the limitations of mechanical recycling. Chemical recycling is the process of modifying the chemical structure of polymeric waste and converting it back into monomers that can be used to make new polymers. Chemical recycling degrades fibers into monomers or building blocks, which are then re-polymerized to produce new fibers of comparable or greater quality. However, chemical recycling runs the risk of preserving or spreading hazardous compounds present in dyes, softeners, anti-wrinkle treatments, and other popular additions. Chemicals included in textile waste have the potential to block recycling operations; nevertheless, our understanding of specific consequences and how much they affect processes is limited. (7)

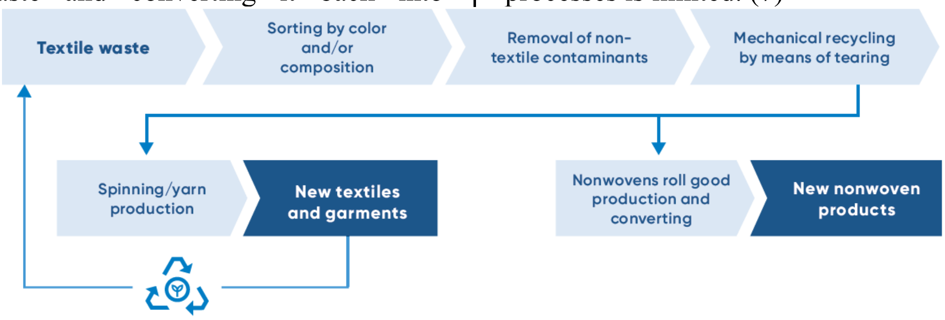


Fig. (2): Recycling process based on mechanical recycling (8)

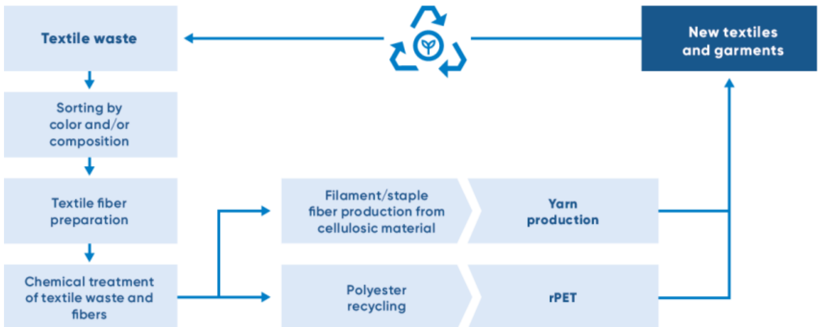


Fig. (3): Recycling process based on chemical recycling (8)

2-2- Circulose® fibers:

Because cellulose-based fibers account for more than one-third of all textile fibers generated each year, cellulosic textile recycling technologies are an appropriate research topic. (9) Aside from these popular fibers, there have been new brands introduced in response to the growing trend of recycling. Since 2017, Renewcell® technology has become a rising brand from Sweden. This procedure employs worn clothes and textile production waste with high cellulose content, including viscose, lyocell, modal, acetate, and other regenerated fibers (also known as man-made cellulosic fibers). Their accessories, including buttons and zips, are removed from the textile material, which is then processed into a slurry.This slurry is sifted to remove contaminants and non-cellulosic substances. This blend, known as Circulose®, is made up of dissolved pulp from 100% recycled textiles that has been dried and packaged in bales before being used in the textile production process. (6) Because cotton and viscose clothing contain a large amount of cellulose, the company mostly recycles them as textile trash. The company's procedure for employing Circulose pulp includes the following steps: (10)

- Renewcell receives and recycles worn-out or out-of-style clothing. The clothing has been torn, unbuttoned, unzipped, and decolored. Clothes are then ripped or shredded into fragments.
- The slurry is filtered to eliminate non-cellulose components, such as polyester and plastic, as well as impurities.
- The remaining material is cellulose, a biodegradable organic polymer found in cotton, green plants, and trees.
- Drying the slurry yields pure Circulose® branded pulp. When the slurry dries, sheets of this particular fiber are generated, ready for new clothes to be manufactured.
- The new material sheets are bundled into bales and supplied to fashion producers for use in textile production as natural fibers.
- A brand creates new garments using Circulose® fibers. Circulose® is a registered trademark held by Renewcell. For the fashion industry, using the trademark is an efficient way to communicate the cyclical tale behind the new outfits.

Fig. (4): Steps of converting textile waste into recycled fibers (10)

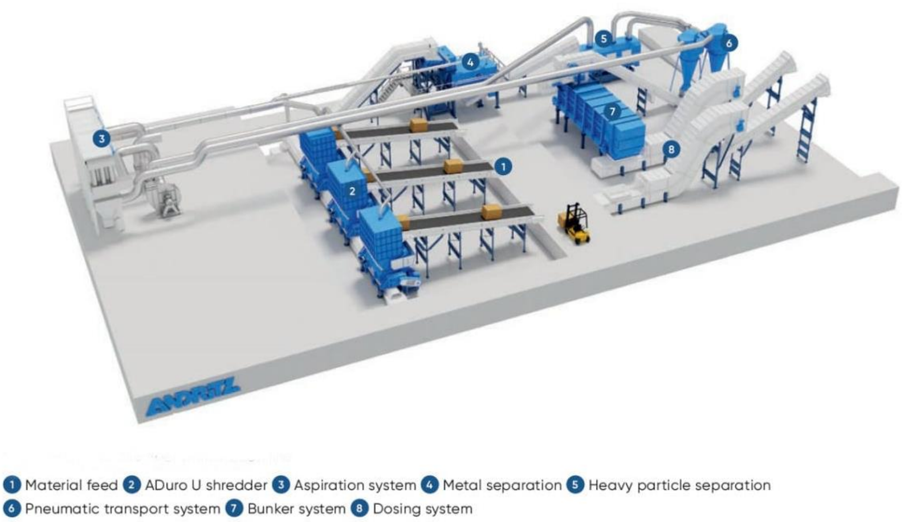


Fig. (5): Example of a textile fiber preparation line (11)

3- Materials and methods:

3-1-1 Materials

The waste from pre – consumer viscose textiles waste was recycled and taken from the Swedish company Renewcell® as a fiber, known as Circulose fiber, and blended with raw cotton filaments to create a 50% Circulose /50% Cotton yarn in DNM textile for spinning, weaving and dyeing factory in new Damietta, Egypt. Then, this yarn was utilized as a weft in the fabrication of denim fabric with different weave structures (3/1 Twill weave, Satin 4 weave, 2/2 Twill weave, and 2/2 Matt weave). The fabrics produced with blended Circulose / Cotton yarn as weft were compared to the fabrics made with 50%:50% blended Tencel/ Cotton yarn as weft, as a raw material already used in the factory in terms of cost and mechanical properties.

Table (1): Cost comparison of Circulose and Tencel fibers

Faber material	Cost USD/Kg
Circulose	2.5
Tencel	3.2

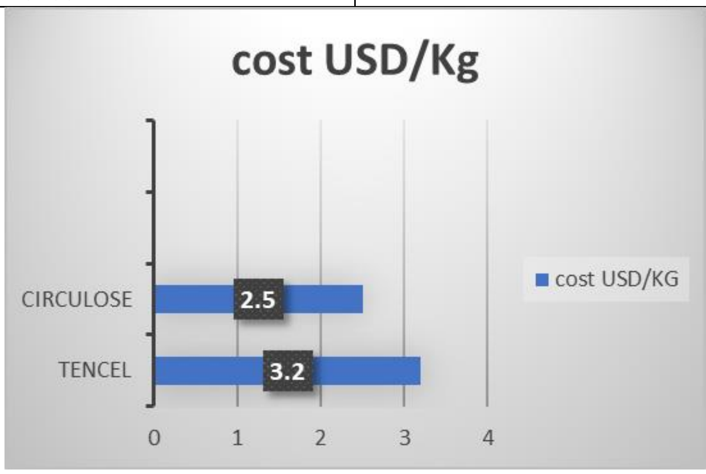


Fig. (6): Cost comparison of Circulose and Tencel fibers

3-2- Methods:

3-2-1- Circulose/Cotton yarn production:

	
(a)	(b)

	
(d)	(c)
	
(e)	(f)
	
(h)	(g)

Fig. (7): Production stages of blended Circulose/Cotton yarn in DNM factory. (a) feeding process, (b)blending, opining, and cleaning process, (c)blended Circulose / Cotton process, (d) carding process, (e)drawing process, (f)roving process, (g) spinning process, and (h) winding process

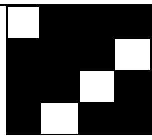
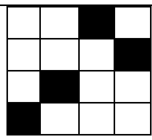
3-2-2- Textile production:

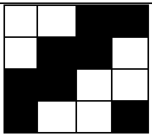
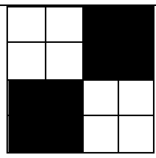
Eight samples were produced, using a Dobby weaving machine with the operational specifications as shown in Table 2. The warp material for all produced samples was 100% 6 Ne cotton; on the other hand, weft materials were 100% 7.5 Ne blended Circulose /Cotton yarn and 100% 7.5 Ne blended Tencel/Cotton yarn as a second weft. Table (3) illustrates the produced samples specifications and numbers.

Table (2): Used machine specification

Loom Type	Picanol Optimax 4 R - 2010
Dobby Type	Dobby Staubli S3020
Reed No.	52
Denting on Reed	4 warp end /teeth
Reed width on loom	185 cm
Warp End /Cm	20.8 warp end/cm
Total Warp End	3848 Warp End
Mechanical Picks	17 pick/cm

Table (3): Materials and structures of the produced woven fabrics

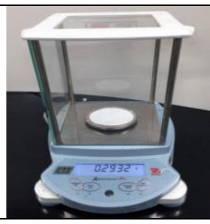
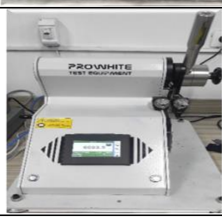
Sample No.	Warp yarn material and count	Weft yarn material and count	Ratio of weft picks	Weave structure
1	Cotton (6 Ne)	Blended Tencel / Cotton (7.5 Ne)	100 %	 3/1 Twill weave
2		Blended Circulose / Cotton (7.5 Ne)		
3		Blended Tencel / Cotton (7.5 Ne)		 Satin 4
4		Blended Circulose / Cotton (7.5 Ne)		

Sample No.	Warp yarn material and count	Weft yarn material and count	Ratio of weft picks	Weave structure
5		Blended Tencel / Cotton (7.5 Ne)		 2/2 Twill weave
6		Blended Circulose / Cotton (7.5 Ne)		
7		Blended Tencel / Cotton (7.5 Ne)		 2/2 Matt weave
8		Blended Circulose / Cotton (7.5 Ne)		

3-2-3- Characterization:

All tested samples were preconditioned at the specified ambient conditions (20°C +/- 2 and 65% +/- 2 RH), following ISO 139, 2005. (12) in the DNM company laboratory. The mass per unit area according to the standard method ASTM D3776. (13) The Tensile Strength Test was determined according to the standard method ASTM D5034. (14) The Elongation Test was determined according to the standard method ASTM D3107. (15) The Tear Strength Test was determined according to the standard method ASTM D1424. (16) and the Stiffness Test was determined according to the standard method ASTM D4032-08. (17)

Table (4): Tests and standards used for the production of fabrics

No.	Test	Device name	Standard specification	
1	Fabric Weight (g/m²)	Sartorius Scale	ASTM D3776	
2	Stiffness (Kg)	SDL Atlas Stiffness Tester	ASTM D4032-08	
3	Tensile Strength (Kg)	Titan3 Device	ASTM D5034 (Modified)	
4	Elongation (%)	Elongation Base Device	ASTM D3107 (Modified)	
5	Tear Strength (gm)	Prowhite Device	ASTM D1424 (Modified)	

4- Results and discussion:

Table (5): Produced fabrics test results

	Variable parameter		Results					
Sample number	Fabric structure	Weft yarn material	Fabric Weight (g/m2)	Stiffness (Kg)	Weft Tensile strength (Kg)	Weft Elongation (%)	Weft Tear Strength (gm)
1	3/1 Twill weave	Blended Tencel / Cotton	467.2	2.27	64.2	4.1	4989
2		Blended Circulose / Cotton	467.7	2.29	63.9	4	4846
3	Satin 4 weave	Blended Tencel / Cotton	466.2	2.27	66.4	4.3	4962
4		Blended Circulose / Cotton	467.3	2.23	64.8	4.3	4926
5	2/2 Twill weave	Blended Tencel / Cotton	465.5	2.39	66.7	4.4	5155
6		Blended Circulose / Cotton	460.1	2.39	66.7	4.3	5195
7	2/2 Matt weave	Blended Tencel / Cotton	447.1	2.98	63.8	4.6	6567
8		Blended Circulose / Cotton	448.5	2.93	61.5	4.6	6487

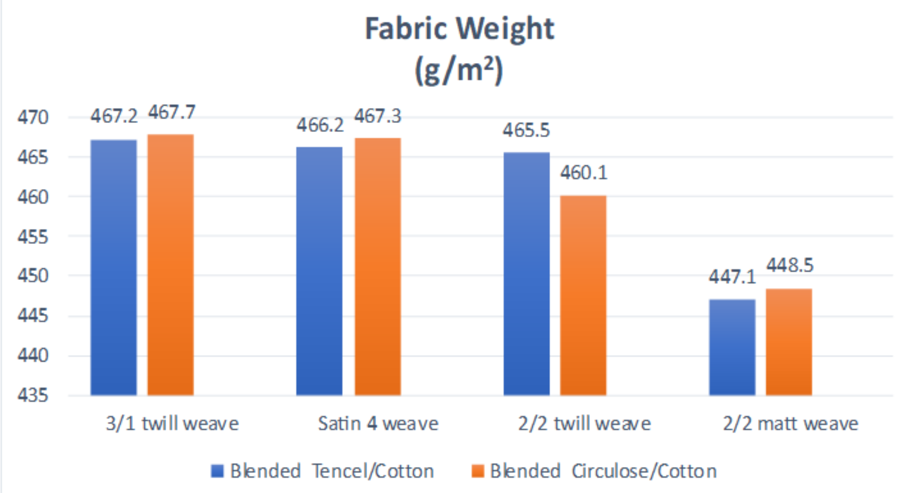


Fig. (8): Results of fabric weight (g/m2)

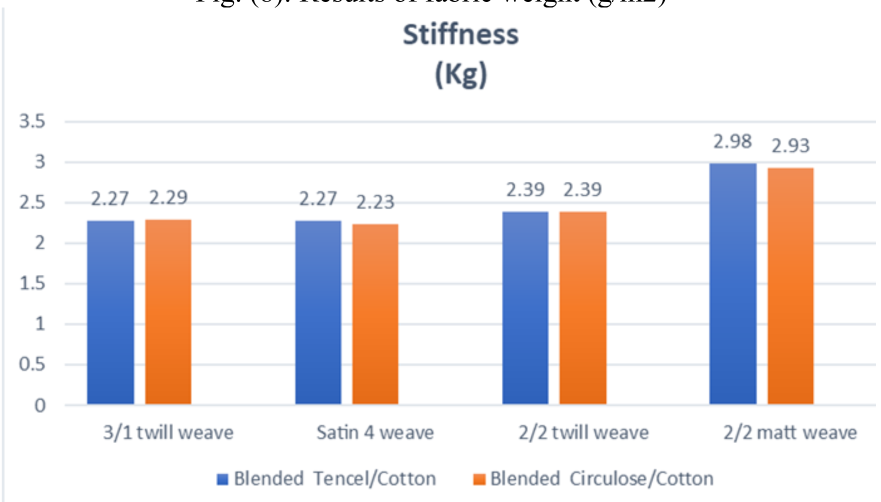


Fig. (9): Results of fabric stiffness (Kg)

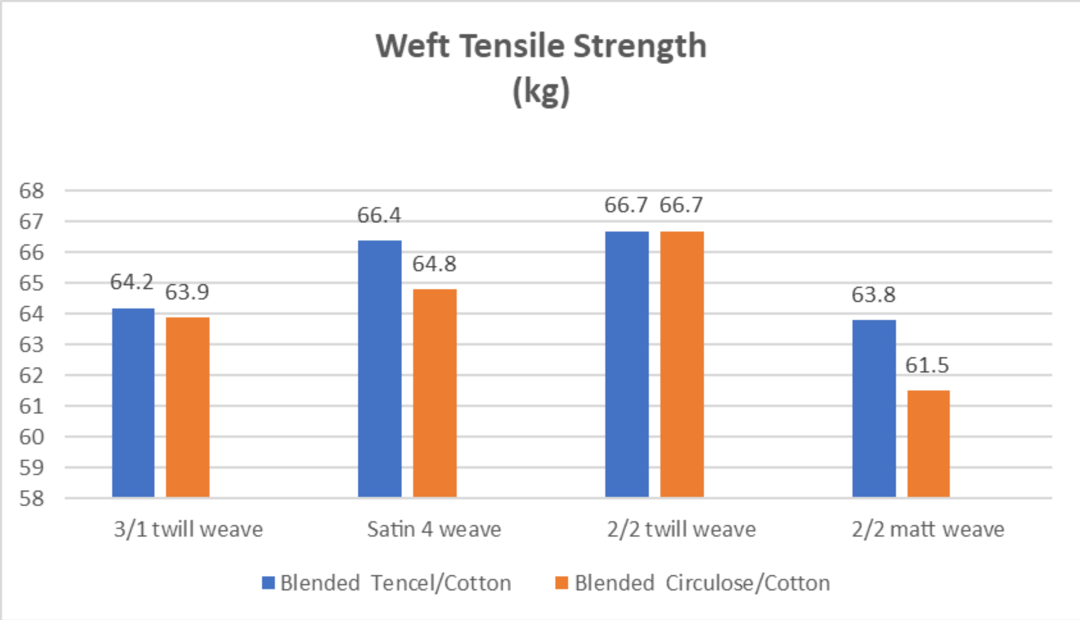


Fig. (10): Results of weft tensile strength (Kg)

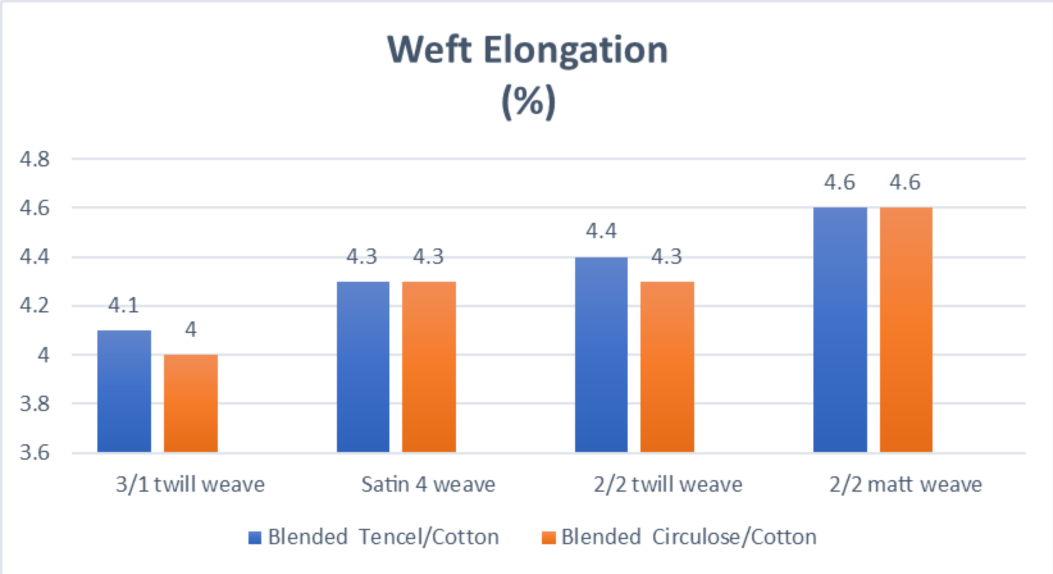


Fig. (11): Results of weft elongation (%)

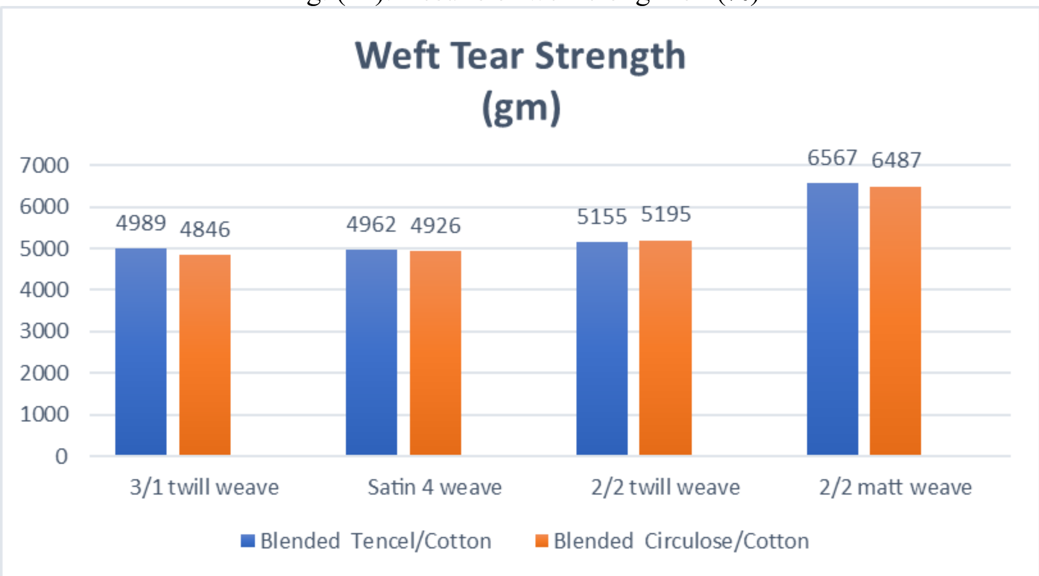


Fig. (12): Results of weft tear strength (gm)

From the previous tables and graphs, it is clear that:

1- The 3/1 Twill weave achieved the highest weight in both blended Tencel/Cotton and Circulose/Cotton fabrics.
2- The 2/2 Twill weave achieved the highest tensile strength in the weft direction in both blended Tencel/Cotton and Circulose/Cotton fabrics.
3- The 2/2 Matt weave achieved the highest stiffness, elongation, and tear strength in the weft direction in both blended Tencel/cotton and Circulose/Cotton fabrics.

Table (6): Evaluation of produced samples

	Variable parameter		Results					
Sample number	**Fabric structure**	**Weft yarn material**	**Fabric Weight (g/m2)**	**Stiffness (Kg)**	**Weft Tensile strength (Kg)**	**Weft Elongation (%)**	**Weft Tear Strength (gm)**	**Quality factor**
1	3/1 Twill weave	Blended Cotton/ Tencel	99.89	76.17	96.25	89.13	75.97	87.48
2		Blended Cotton/ Circulose	100	76.85	95.8	86.96	73.79	86.68
3	Satin 4 weave	Blended Cotton/ Tencel	99.68	76.17	99.55	93.48	75.56	88.88
4		Blended Cotton/ Circulose	99.91	74.83	97.15	93.48	75.01	88.08
5	2/2 Twill weave	Blended Cotton/ Tencel	99.53	80.2	100	95.65	78.49	90.77
6		Blended Cotton/ Circulose	98.38	80.2	100	93.48	79.11	90.23
7	2/2 Matt weave	Blended Cotton/ Tencel	95.59	100	100	100	100	98.25
8		Blended Cotton/ Circulose	95.89	98.32	92.2	100	98.78	97.04

Fig. (13): Radar diagram results of 3/1 Twill weave

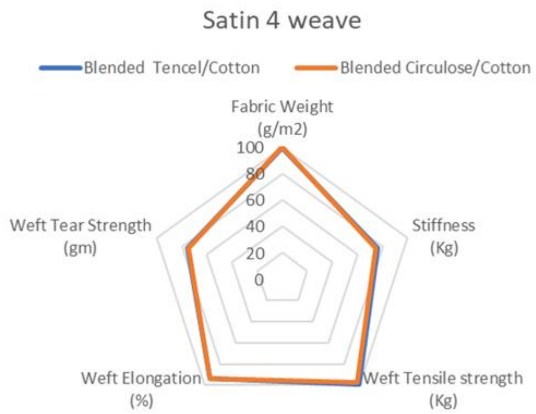


Fig. (14): Radar diagram results of Satin 4 weave

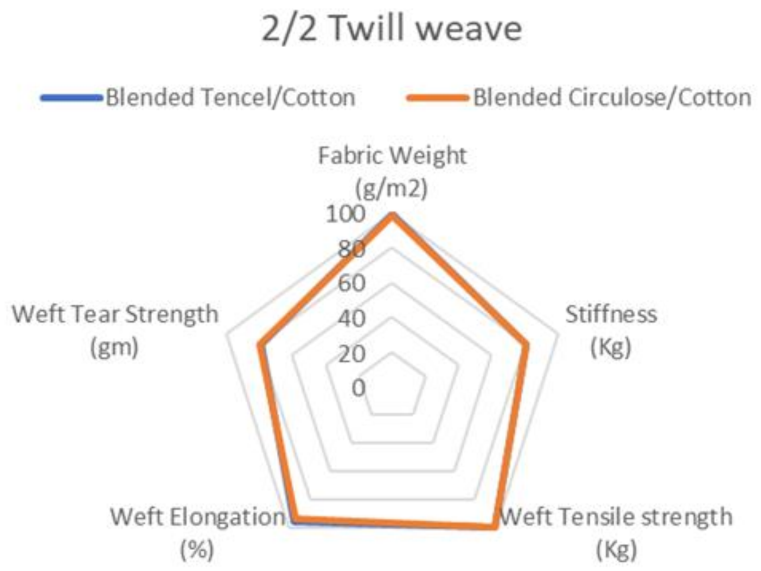


Fig. (15): Radar diagram results of 2/2 Twill weave

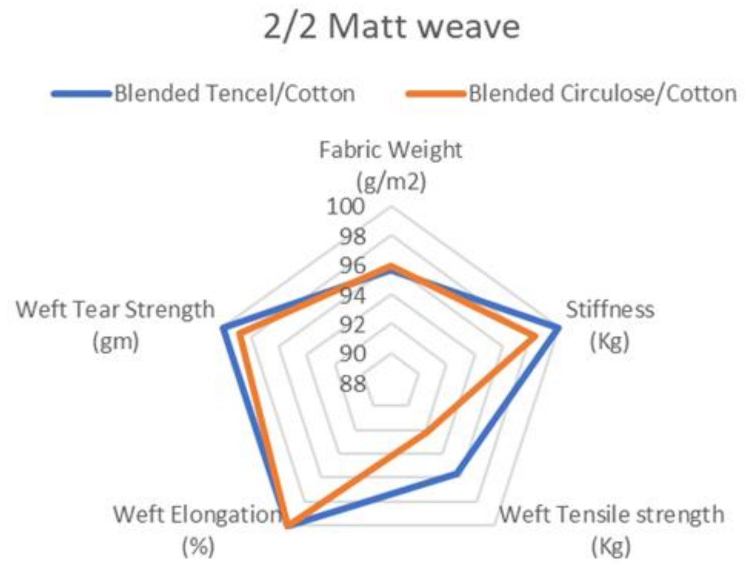


Fig. (16): Radar diagram results of 2/2 Matt weave

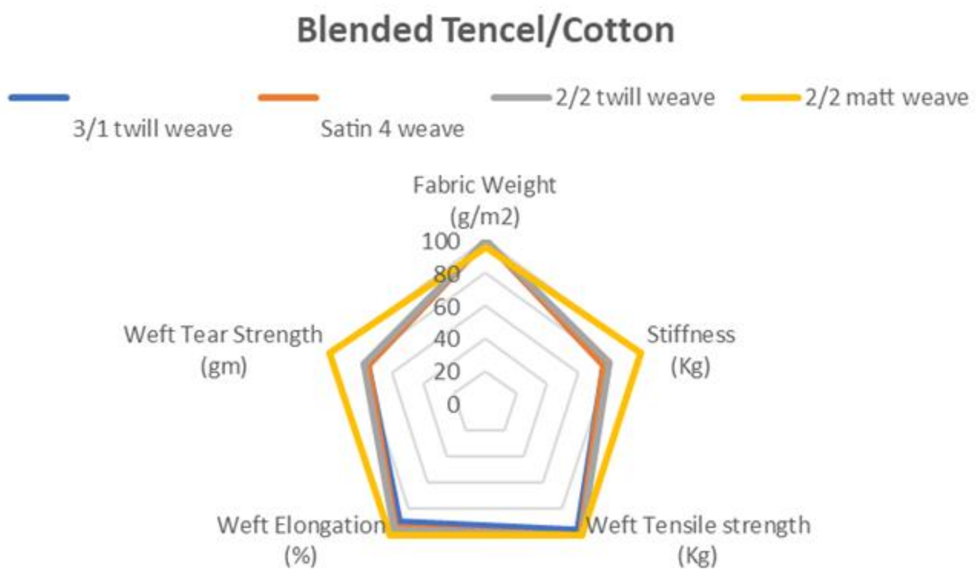


Fig. (17): Radar diagram results of blended Tencel/ Cotton fabric

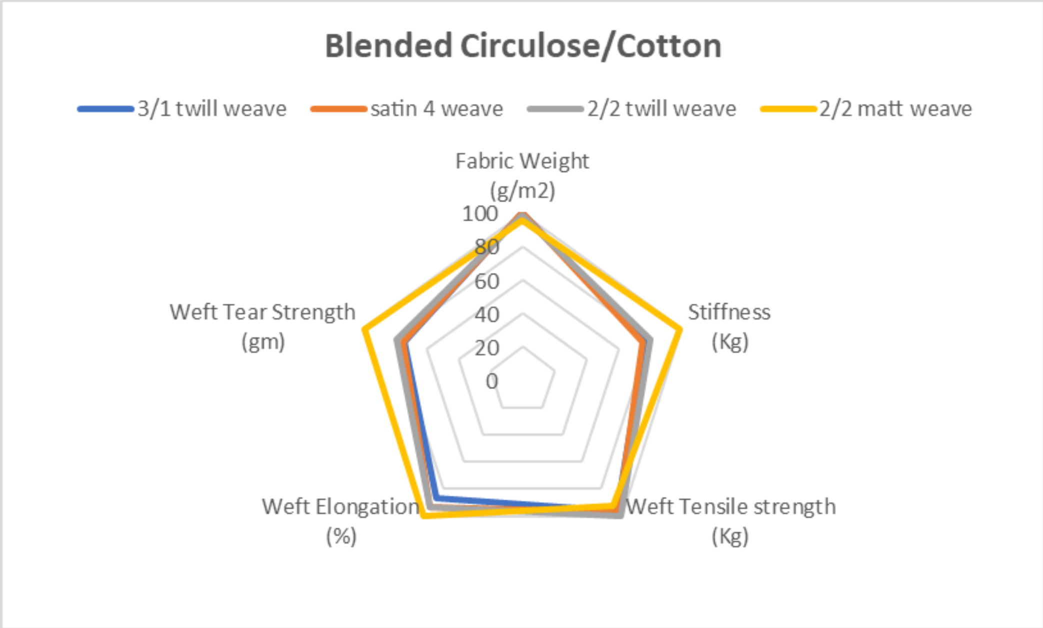


Fig. (18): Radar diagram results of blended Circulose/Cotton fabric

From the table of relative values and quality coefficients, it is clear that:

1- The 2/2 Matt weave achieved the highest quality coefficient in mechanical properties.
2- The samples produced from blended Circulose/Cotton achieved quality coefficient results convergent with those made from blended Tencel/Cotton in mechanical properties for all weave structures produced.
3- Both blended Tencel/Cotton and Circulose/Cotton achieved the highest quality coefficients for the 2/2 Matt weave fabrics.
4- The blended Circulose/Cotton achieved a quality coefficient convergent with Tencel/Cotton, with a difference of 1.21%.

Recommendations:

1- Interest in textile waste as a vital resource as an alternative to raw materials used in textile manufacturing.
2- Expanding the use of textile waste as a primary source in the manufacture of low-cost textiles as an alternative to those made from higher-cost raw materials.
3- Expanding the scope of factories that provide textile waste recycling technology as a basic industry in the Arab Republic of Egypt.

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