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Research Article

Recycling textile industry waste materials: fabrication, characterization, mechanical and thermal performance analysis of developed non-woven interlining

Md. Washim Akram[1], Sayed Hasan Mahmud[2*] and Shanzida Easmin[3]

[1]Department of Fashion Design and Apparel Engineering, National Institute of Textile Engineering and Research (NITER), Nayarhat, Savar, Dhaka, Bangladesh
[2]Department of Textile Engineering, National Institute of Textile Engineering and Research (NITER), Nayarhat, Savar, Dhaka, Bangladesh
[3]Department of Textile Engineering, Bangabandhu Textile Engineering College (BTEC), Kalihati, Tangail, Bangladesh

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Abstract

In the last few years, the shortage of natural resources, the energy crisis and environmental issues have threatened the world simultaneously. Furthermore, the manufacturing sector is facing the most vulnerable economic conditions due to high raw material, energy and operating costs. It is critical to emphasize cost-cutting without sacrificing sustainability. Herein, it has been attempted to recycle textile waste material into non-woven interlining. The fabrication process includes the collection of textile waste materials, bleaching the fabric, garneting to loosen fibrous and conversion to nonwoven web form through an aqueous solution of fibrous flock with a mixture of epichlorohydrin as a cross-linker. Three nonwoven interlinings were successfully developed from 100% cotton, 50% polyester/50% cotton and 75% polyester/25% cotton blended ratio of waste fabric. Linear weight, thickness, tear strength, tensile strength, Eb%, bursting strength and TGA of these samples are assessed. Furthermore, we compare the recycled sample cost and investigate the seam performance of developed samples made from various woven twill fabrics. It is observed that the developed samples show satisfactory performance and are cheaper than the current market price, having potential scope in clothing manufacturing as well as offering a sustainable approach to the environment.

Keywords: *Climate change, recycling, waste materials, textile industry, non-woven interlining, TGA, seam efficiency*

1. Introduction

Environmental issues, including global warming and waste management, have become increasingly crucial over the last few decades. As a result, it is acknowledged that our society's current approach to product waste management is not environmentally sustainable. In reality, one of the most important issues facing manufacturers today is keeping the environment safe. In order to remain competitive in their markets, they must lessen the environmental effects of their products [1]. The textile and apparel industries receive a significant amount of condemnation for their supply chain operations, which have an adverse effect on the environment in terms of waste production, carbon footprint, and resource use [2]. The production of textiles and clothing requires a significant amount of energy, water, and other natural resources, and it also produces a substantial amount of waste [3, 4].

Responses to the recent textile and apparel industry challenge have mostly emphasized sustainable practices to alleviate the climate crisis and environmental impact. A significant quantity of waste is produced during each stage of the manufacturing process, including spinning, knitting/weaving, dyeing, clothing manufacture, and finishing, as a result of rising customer demand for fashion and the fast fashion trend [5].

Researcher S. Kavitha *et al.* revealed the main causes of waste in the garment industry due to delayed shipment, overprocessing, overproduction, and correction activities, besides stating that reuse is the best solution for proper waste management as well as mitigating the pressure on virgin resources [6].

In the production of clothing and other textile products, enormous amounts of waste are generated annually. Cotton as well as its blends with man-made fibers is a key contributor to textile waste. For the textile sector, disposing of such immense quantities of waste is becoming a bigger issue. Environmental issues arise when textile waste is buried or dumped in a landfill. The manufacturing and consumption of

*Corresponding author's ORCID ID: 0000-0003-0870-1867
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clothing have dramatically expanded in response to rising consumer demand for fashion and the "fast fashion" trend [7]. Fast fashion is one of the most wasteful sectors in the world due to its rapid manufacture and supply of clothing, which accounts for 10% of the carbon footprint, 35% of all microplastics and microfibers, 31% of plastics in the marine environment, and the second-highest water consumption after agriculture [8]. To replace rapid fashion concepts and limit the production of textile waste, Burch et al. recommend micro fashion [9]. According to several studies, the worldwide textiles sector produced over 92 million tons of textile waste in 2014, of which only a small fraction was recycled or reused and a large portion was disposed of in landfills or burned [10]. Bangladesh's textile and garment industries are estimated to produce over 577,000 tons of waste, of which 250,000 tons, or nearly half, are cotton waste that is worth 100 million dollars and perfectly recyclable [11]. Additionally, it is predicted that between 2015 and 2030, the amount of global textile waste would rise by 60% annually, adding an extra 57 million tons of waste per year to reach a total of 148 million tons per year [12]. At the present, Bangladesh is significantly dependent on the importation of textile fiber. A total of 1.63 million metric tons of staple cotton fiber were imported into the nation in 2019, at an estimated cost of US$3.5 billion. Besides The textile and clothing sector had a USD 1.3 trillion market value in 2015. 53 million tons of textile fiber were used, of which 73% were landfilled or burned. A loss of materials worth more than USD 100 billion occurs annually because less than 1% of material is recycled for new clothes [13]. It is regrettable that our competitors, such as Vietnam, Indonesia, and India, are claiming around $4.5 billion in revenue from the recycling sector. Recycling is frequently regarded as the most effective waste management strategy for protecting our planet's ecosystem. For many applications, particularly with metals, glassware, or polymers (including synthetic fiber materials), recycling only reduces the rate of environmental deterioration, even though 99% of used textiles are recyclable [14]. The development of recycling methods for industrial waste products has attracted more interest in recent years with the intention of preserving the environment. Because synthetic fiber doesn't degrade in the environment, it poses a threat to all living things. A healthy environment requires the development of appropriate waste management strategies for all varieties of waste [15]. The 2025 Recycled Polyester Challenge, which was introduced in 2021, focuses on manufacturers to commit to increasing the percentage of recycled polyester (PET) used in garments from 14% to 45%. The Textile Exchange's 2017 recycled polyester commitment served as the foundation for the 2025 recycled polyester challenge. With the ultimate objective of reaching a critical mass and recycling 90% of all polyester by 2030, brands are encouraged to utilize 80–100% PET. Every year, consumers in the European Union (EU) trash over 5.8 million metric tons of textiles. Only 1.5 million metric tons, or 25%, of these textiles are recycled by enterprises and voluntary organizations [16]. An investigation reveals the constructs of consumer creativity, fashion consciousness, and environmental concern, and it looks at the connections between these factors and consumer interest in upcycling techniques and upcycled clothing purchases [17, 18]. Strong economic motivations for developing new techniques to recycle excess or unused textile material include rising costs connected with the availability of raw resources and steadily rising textile product usage. At "cut and sew" factories where clothing is produced, significant volumes of textile waste, clippings, and loose sample scraps are produced [19, 20]. These leftovers make up about 15–30% of the various materials made for clothing. These textile trimmings and scraps become garbage and are dumped in landfills unless they are recycled into valuable products. Due to the smaller market potential, even recycling into insulating materials or non-woven matting is restricted [19, 21]. Many businesses upgraded their production processes to utilize alternative materials for their products and began looking for new markets as a result of environmental concerns. Numerous businesses are seeking applications where waste materials may be a material with additional value due to the huge output of waste fibrous materials.

Recently, the industry of sustainable fashion has been one that is voluntary, as seen by the commitments made by several leading clothing brands [18, 22, 23]. Companies like Zara, the largest apparel brand in the world and the second-largest retailer in the world after H&M, have pledged to utilize 100% recycled and sustainable materials by the year 2030 as part of their sustainability targets [9, 24].

Several researchers have shown their efforts to continue the sustainable approach in design creation, manufacturing stage through re-engineering and diversification. Researcher Tomohiko Sakao suggests the QFD-centered (quality function design) design approach for the development of environmentally conscious products [1]. Rajesh Mishra et al. used web bonding techniques to create a non-woven composite material out of leftover cotton fiber they had garnered and combined with polypropylene [25]. Another researcher, Ana Briga-Sá, demonstrates another environmentally friendly method by creating thermal insulating construction materials out of used acrylic woven fabric, which improved thermal behavior by 30% to 50% [16].

In this research work, we collected textile waste fabrics and recycled them into non-woven sewn interlining that will be used during clothing production as a trim. After that, examine the characterizations (such as, GSM, thickness, tear strength, tensile strength, Eb%, bursting strength and TGA, etc.) of the developed samples as well as conduct an experiment with common woven twill fabrics to evaluate the sewing performances (such as seam strength, efficiency, etc.) in a realistic manner.

Experimental

Materials and sample preparation

Fabricated nonwoven interlining

We collected three types of cutting waste fabric from Southeast Textiles Pvt. Ltd., Bangladesh. Their fiber contents are 100% cotton, 50% cotton/50% polyester and 75% polyester/25% cotton and Epichlorohydrin from Tasnim Chemical Complex Ltd., Bangladesh. After gathering all of the fabrics and chemicals, we began the process of creating nonwoven interlining. In this study, our aim is to reuse the cutting waste from the apparel industry considerably and to develop a sustainable nonwoven sewn interlining. We also used our developed interlining on two different types of commercially available woven fabric and determined the seam efficiency to evaluate the fabricated sample's effectiveness in industrial use as well as its cost effectiveness.

We collected the waste fabric and bleached it with H_2O_2 at 90oC temperature for 30 min. After that, cut the bleached fabric into small pieces to make fiber flock. Mix 0.5 mL of epichlorohydrin in water, stir the mixture well for a minute. Then mix the fabric properly. Then immerse the wooden mesh frame (34 cm x 21 cm) in the water bowl. After that, raise the frame evenly with fiber flock, remove excess water and transfer it to a flat surface. Finally, dry the sample in the oven and apply manual screw pressure for smoothness, then cure the fabricated samples.

Figure 1: Epichlorohydrin and Waste Fabric Collection Area.

Table 1: Properties of Epichlorohydrin [26].

Parameter	Value
Chemical formula	C_3H_5ClO
Molar mass	92.52 g/mol
Appearance	colorless liquid
Odor	garlic or chloroform-like
Density	1.1812 g/cm^3
Melting point	−25.6 °C (−14.1 °F; 247.6 K)
Boiling point	117.9 °C (244.2 °F; 391.0 K)
Solubility in water	7% (20°C)
Vapor pressure	13 mmHg (20°C)

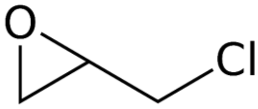

Figure 2: Epichlorohydrin skeletal structure [26].

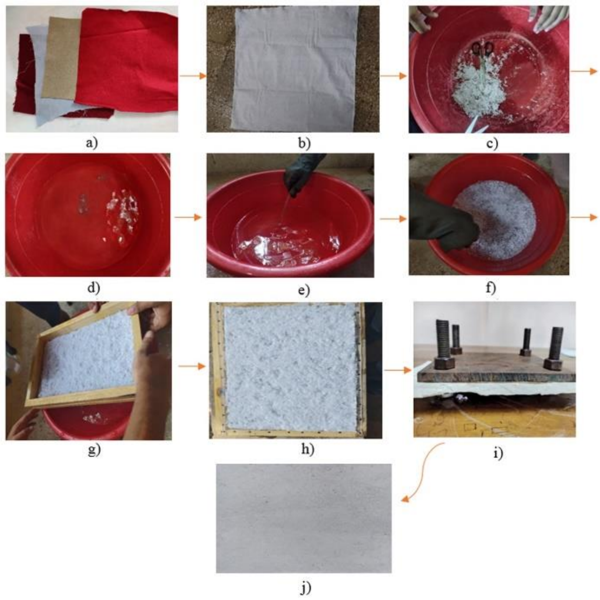

Figure 3: Graphical process flow chart of interlining making process a) waste fabrics b) bleached fabric c) cutting into small pieces d) adding water and chemical e) mixing water and chemical f) add cut fabric pieces in water g) rinse the frame evenly h) transfer into flat surface i) applying pressure j) final product.

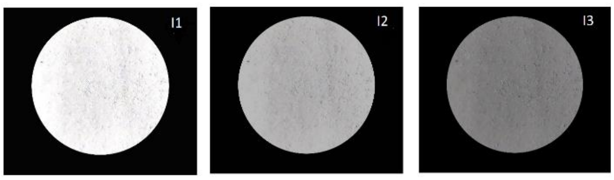

Figure 4: Image of fabricated interlining (I1) bleached 100% cotton waste material; (I2) 50% cotton/50% polyester mixed waste materials; (I3) 75% polyester/25% cotton mixed waste materials.

Figure 4 shows the visual appearance of interlining made from waste material. There are three samples of interlining developed from textile waste. The visual appearance of the samples described above is nearly identical. But the sample (I1) 100% cotton bleached interlining shows more whiteness than the polyester/cotton blended developed samples (I2) and (I3). These samples have darker shades, but they can be used as garment trims without issue.

Fabric and nonwoven sewn interlining assemblies

For seam preparation, we applied the fabricated three types of interlining sample- I1, I2, I3 on the two types of commercially available fabric sample- F1, F2. Five samples from each stitch type (lock stitch- 301 and chain stitch- 401) and polyester sewing thread count (60 tex) with SPI (12) were used to do the seam strength study and considered the mean value.

Table 2: Specifications of sample fabrics.

Fabric Specification	F1	F2
Fiber Content	100% Cotton	95% Cotton + 5% Elastane
Weave Type	3/1 RH Twill	3/1 RH Twill
Warp Count (Ne)	30 Carded	40 Carded
Weft Count (Ne)	20 Carded	24 Carded
Ends per inch (EPI)	110	160
Picks per inch (PPI)	80	112
Fabric width (Inch)	56”	57”
GSM	176.7	201.5

Characterization

Fabricated sample weight

The measurement of interlining mass per unit area was determined using the ASTM D3776 [27] Option C test standard. We used Option C, which was a tiny sample. We created a test specimen with a minimum surface area of 130 cm^2 (20 in^2). The test sample specimen was cut using a GSM cutter machine. The created interlining sample for each kind of sample was weighted using five subsequent specimens, and the mean value was then calculated to calculate the GSM value.

Thickness

We utilized a precise thickness gauge and the ASTM D1777 [28] standard to measure the thickness of manufactured samples in the lab. The testing equipment used was a SCHMIDT Ruu-30-a textile material thickness tester of German origin. The sample was 130 cm^2.

Tear Strength

We employed the falling-pendulum type (Elmendorf) equipment to test the ripping strength of samples in accordance with ASTM D1424 [29]. An interlining specimen is torn using the Elmendorf test device's falling pendulum. The peak follow-through angle of the pendulum following the tearing action is used to calculate the amount of energy needed to complete the tearing process. The amount of energy that has been transmitted into ripping the specimen increases with a decreased follow-through angle. 100x75 mm was the size of our sample. The JAMES HEAL Tear Tester (Model: 1555ELMATEAR), UK, was used as the testing tool.

Tensile Strength

The breaking strength and elongation of our interlinings and textiles were tested using the ASTM D5034 [30] standard. This test method outlines a process for employing the grab technique to measure the maximum force and the elongation at maximum force of textile materials. 150x100 mm was the size of our sample. James Heal Universal Strength (Model: 1410TITAN-5), UK, provided the testing equipment.

Bursting Strength

To evaluate the bursting strength of our materials, we employed the ASTM D3787 [31] standard. When a cloth is under strain, it immediately starts to expand in every way that is imaginable. When the pressure is gradually increased, the fabric eventually reaches a pressure limit and bursts. Burst strength refers to the upper limit of pressure. For this test, the specimen should be cut so that its diameter is increased by half an inch compared to the clamp ring. Bursting Strength Tester, Model: 338E, Brand: MESDAN-LAB, Italy, was the testing equipment used.

Seam strength

In order to prepare and test samples, the experiment was conducted according to ASTM standards. The seam strength investigation was conducted using six samples of each stitch type (lockstitch-301 and chain stitch-401), polyester sewing thread count (60 tex), and stitch density (12), and the mean value was taken into consideration. Following that, according to ASTM D1683 standard, sewn fabrics were evaluated for the effectiveness and strength of their seams on a James Heal tensile strength testing machine at a speed of 305 mm/min and a gauge length of 75 mm [32]. Each sample underwent a total of five tests in a row in the warp direction. A universal tensile strength testing equipment was used to assess the tensile strength of two distinct kinds of un-seamed fabrics (F1, F2). 10 cm x 10 cm of the base fabric were cut out and sewn with a seam allowance of 1 inch in the warp direction to test the strength of the seams.
Seam efficiency was measured by:
Seam efficiency (%) =
(Seamed fabric tensile strength / Un-seamed fabric tensile strength) × 100

Thermogravimetric analysis (TGA)

We have used the ASTM E1131 [33] test standard for TGA. The prepared mats' thermal behavior was assessed using a thermal analyzer (SDT 650, Discovery, USA) at temperatures between 50°C and 600°C with a continuous heating rate of 50°C/minute. To test the properties of the sample, about 5 mg of it was heated.

Results and Discussion

Table 3: Linear weight and thickness of the fabricated interlining samples.

Interlining Content	Interlining Sample	Weight (gm/m²)	Thickness (mm)
100% cotton	I1	34.11	0.11
50% cotton 50% polyester	I2	35.65	0.12
75% polyester 25% cotton	I3	37.12	0.14

Table 4: Tear strength, tensile strength, elongation at break and bursting strength of the fabricated interlining samples.

Interlining Sample	Tear Strength (N)	Tensile Strength (N)	Elongation at break (%)	Bursting Strength (N)
I1	1.53	19.87	8.21	1172.31
I2	1.83	22.54	7.37	1053.91
I3	2.30	24.52	4.84	814.77

Table 5: Linear weight, thickness and fabric strength of the fabric samples.

Fabric Content	Fabric Sample	Weight (gm/m²)	Thickness (mm)	Fabric Strength (N)
100% Cotton	F1	176.7	0.17	284.81
95% Cotton + 5% Elastane	F2	201.5	0.24	307.59

Table 6: Linear weight, thickness, seam strength, seam efficiency and elongation of the fabric and interlining assemblies for lock stitch-301, SPI- 12, thread count-60 tex.

Fabric and interlining assemblies	Thickness (mm)	Seam Strength (N)	Seam Efficiency (%)	Elongation (%)
F1I1	0.28	137.23	48.18	13.32
F1I2	0.29	141.76	49.77	12.91
F1I3	0.31	148.44	52.12	10.53
F2I1	0.35	151.79	49.35	17.46
F2I2	0.36	167.21	54.36	14.57
F2I3	0.38	173.09	56.27	13.81

Table 7: Linear weight, thickness, seam strength, seam efficiency and elongation of the fabric and interlining assemblies for Twin needle chain stitch-401, SPI- 12, thread count-60 tex.

Fabric and interlining assemblies	Thickness (mm)	Seam Strength (N)	Seam Efficiency (%)	Elongation (%)
F1I1	0.28	148.32	52.08	20.52
F1I2	0.29	155.75	54.69	18.64
F1I3	0.29	163.21	57.30	18.12
F2I1	0.35	159.65	51.90	23.66
F2I2	0.36	178.33	57.98	21.44
F2I3	0.36	187.65	61.01	18.33

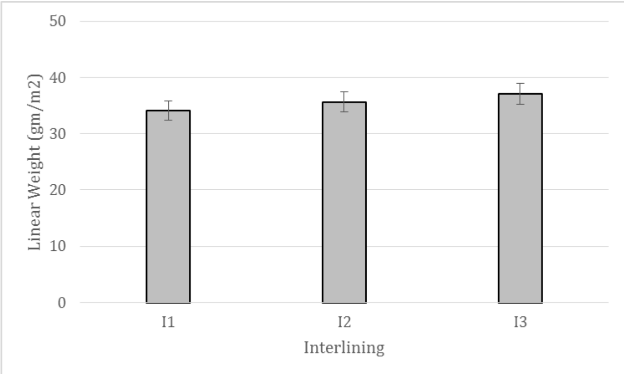

Figure 5: Linear weight variations of fabricated interlining samples.

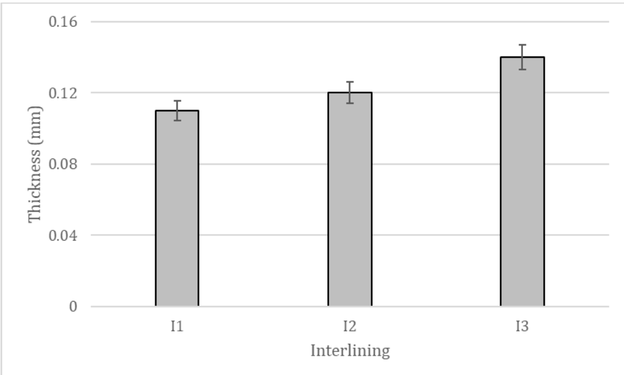

Figure 6: Thickness variations of fabricated interlining samples.

The linear weight and thickness of the interlining are revealed in the figures 5 and 6, where the GSM and thickness of the 100% cotton sample (I1) are slightly less than the polyester/cotton blended samples (I2, I3). This is because, due to pressing in the finishing stage of sample development, the more amorphous structure of a 100% cotton sample can't withstand high pressure. The polyester/cotton blended samples, on the other hand, have a more crystalline structure and are more stable, which is why they have slightly more GSM and thickness.

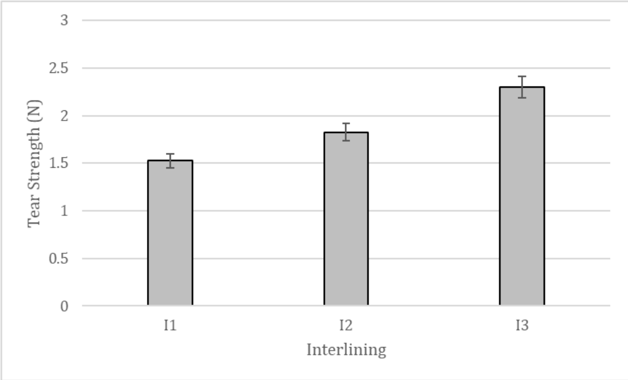

Figure 7: Tear strength variations of fabricated interlining samples.

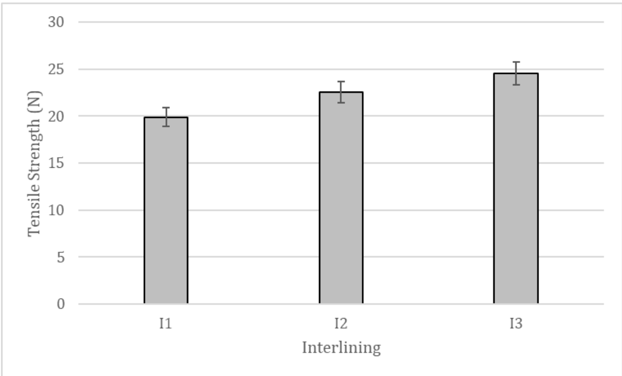

Figure 8: Tensile strength variations of fabricated interlining samples.

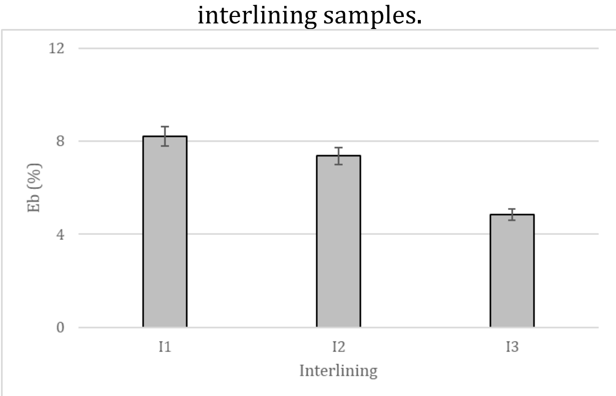

Figure 9: Eb% (elongation at break) variations of fabricated interlining samples.

Figures 7, 8, and 9 depict the tear strength, tensile strength, and elongation at break (%) of developed samples, respectively, where the tear and tensile strengths of polyester/cotton blended samples (I2, I3) exceed those of a 100% cotton sample. Because, by mixing polyester with cotton, the structure becomes more crystallized and the intermolecular bonds within the polymer matrix become stronger, they can resist the high external breakage load (N) compared to the 100% cotton sample. Moreover, notice that the amount of polyester contributes significantly to increasing the strength; that's why samples I2 and I3 show gradual increases in strength. On the other hand, due to having more crystal nature in the poly/cotton blended samples (I2, I3), they show a gradual decline in nature in Eb% rather than the 100% cotton sample (I1).

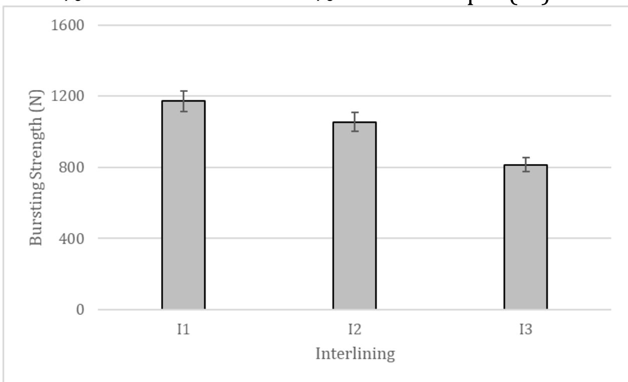

Figure 10: Bursting strength variations of fabricated interlining samples.

The bursting behaviors of developed samples are depicted in Figure 10. Generally, breaking strength and thickness, as well as the Eb% of the sample, contribute to the bursting strength. The more a sample can elongate its structure, the more external load it can withstand before it bursts. Due to having a more amorphous region, the 100% cotton sample (I1) shows satisfactory Eb%, which explains why bursting strength is higher compared to the poly/cotton blend samples (I2 and I3).

Thermogravimetric analysis

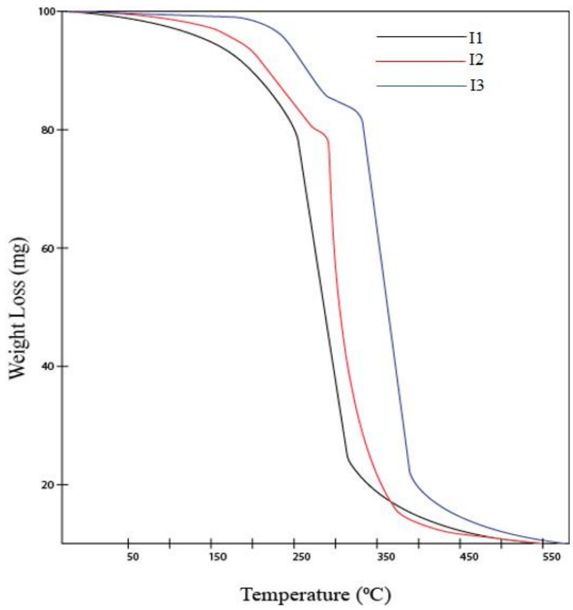

Figure 11: TGA of fabricated interlining samples.

Thermogravimetric analysis is recognized as one of the most important tests for establishing a material's thermal stability. Figure 11 shows the temperature behavior of Sample-I1 (100% cotton) Sample-I2 (50:50 poly/cotton blend and 75:25 poly/cotton blend). In Sample-I1, when the temperature reaches at 140^0C ignition is started. Due to continuous temperature raising, it begins to weight loss slightly. But when cross the temperature level 260⁰C-310⁰C it turns to combustion stages and significant amount of weight losses due to having more amorphous region. On the other hand, the poly/cotton blend sample exhibited two distinctive mass loss peaks. The normal degradation onset temperature of polyester is 410°C but because sample I2 contains 50% cotton, cotton acts as the initial source of ignition at 170°C and loses some weight, but when the temperature reaches the melting point at 270°C to 360°C, significant weight loss is caused by thermal decomposition into CO and carbonaceous char. In terms of stability, sample I3 of the polyester/cotton (75/25) blends is better than sample I2, which shows thermal melting stability up to 385 °C.

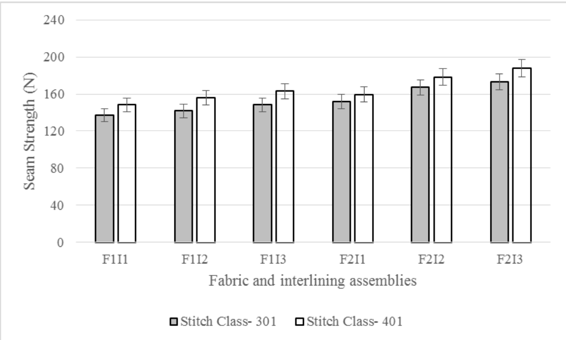

Figure 12: Seam strength comparison of developed fabric and interlining assemblies' samples.

Figure 13: Seam efficiency comparison of developed fabric and interlining assemblies' samples.

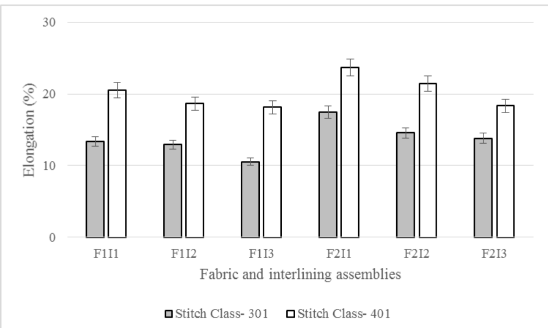

Figure 14: Elongation comparison of developed fabric and interlining assemblies' samples.

After fabrication interning (I1, I2, I3), the sewing performance were tested with two different types of woven fabrics (F1 and F2), following stitch class-301 and 401 by keeping the SPI-12 is constant. In the above figure 12, 13 and 14, reveals the seam strength, efficiency% and elongation% data respectively. Generally, all the constituent material's (such as, stitch type, fabric type, interlining fabric behaviors) that is used to make a seam have significant response to a seam strength and performances. Here the above figure shows that in all cases, stitch class-401 shows better seam strength than stitch class-301. Since, stitch class 401 follow the interlacing and interloping techniques structurally that allows its more extensibility that's why shows high elongation% and more seam strength as well as better efficiency% for less seam rupture tendency. On the other side, stitch class-301 is formed by interlacing manner that is less extensible and highly tight in nature that's why breakage by low force in both directions compared to stitch clas-401. Besides, the fabric and interlining materials quality of a seams behave as the more the GSM of fabric and stable nature of interlining fibrous materials the more will be seam strength and efficiency as well as shows less elongation that's why the all-combined samples made from fabric (F2) and interlining sample (I3) and Stitch class-401 exhibits high strength and efficiency.

Cost analysis

In apparel making, interlining plays an important role in retaining the proper shape of a specific portion of a product. The main materials for making interlining are cotton, polyester, etc. Manufacturers import massive amounts of fibrous materials to meet high interlining demand, which is an expensive and time-consuming process. However, the garments section wastes a significant amount of textile and rejects clothing on a daily basis, as well as an abundance of post-consumer clothing available in the "Jhut" market that was recycled in a negligible amount. Based on our experiments, we proposed our recycled non-woven interlining manufacturing cost in Table 8.

Table 8: Cost consideration of fabricated interlining samples from cutting waste.

Cost areas	Product cost/yd
Waste fabric	4 cents/yd
Chemicals cost	4 cents
CM	3 cents
Transport and miscellaneous	1 cent
Total Cost	12 cents

From, the table we can easily understand that by making interlining from waste material is very cheap. It takes only 12 cent/yd where as traditional method of interlining takes around 22-25 cents/yds [34].

Conclusion

In this research work, textile cutting waste materials are recycled into nonwoven interlining for apparel production as a trim. During the fabrication process, all parameters have been controlled faithfully. After the fabrication process, the visual appearances, GSM, thickness of materials, tensile strength, tear strength, bursting strength, and TGA of the developed samples were examined. Whereas, we found the 100% cotton bleached sample exhibited poor strength compared to the 75% polyester/25% cotton sample. Because polyester is crystalline in nature, the 75% polyester/25% cotton sample demonstrated greater strength than the 100% cotton sample. Furthermore, the recycling cost of the developed sample (12 cents/yd) was cheaper than the current market price (22-25 cents/yd) which is almost half the price. We also applied the fabricated interlinings to two commercially available woven fabrics. We measured the seam efficiency of the developed samples and discovered that the 95% cotton/5% elastane fabric and 75% polyester/ 25% cotton interlining assemblies were the most efficient. In conclusion, considering the easy recycling process and cheap price, we can easily recycle textile cutting waste material into non-woven sewn interlining for commercial usage.

Conflict of Interest

The authors have declared no conflict of interest.

Compliance with Ethics Requirements

This article does not contain any studies with human or animal subjects performed by any of the authors.

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