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Study of mechanical properties and characteristics of eco-fibres for sustainable children's clothing

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Abstract

The aim of this paper is to study the application of eco-fibres as a new approach to achieve the multifunctional design for children's clothing toward sustainability in the clothing industry. In this regard, this study focuses on the evaluation of the fabrics' mechanical properties including tensile strength and microstructural details as critical points for multifunctional children's clothing purposes. The eco-fibre fabrics studied are organic cotton twill and recycled polyester. Studies have proven that frequent laundering and dry-cleaning result in increased pilling. Furthermore, high quality of colour fastness properties was found in 100% organic woven cotton fabric and recycled polyester fabric printed by non-harmful dyes. Organic cotton fabric is found to offer minimum tear resistance due to the lower strength of cotton fibres. The study found very good physical properties of organic cotton fabric during the mechanical test as well as recycled polyester fabric, which are also safe and eco-friendly. Therefore, these materials are suitable to be used in sustainable clothing design, as it is also a means towards the reduction of environmental pollution and tackle resource depletion associated with the clothing industry.

1. Introduction

Sustainable fashion for children's clothing is in high demand in today's society. Sustainability and multifunctional design use integrated technology and takes into account the economic, environmental and social factors to improve the functionality of products. Indeed, this is based on the consciousness of the ecological environment. This is important as it meets the function, quality and cost of the product while considering environmental attributes, social health and economic issues during the product's entire lifecycle. Additionally, children's clothing design should meet the physical and psychological needs of new shapes, unique appearances and others to attract children [1]. Therefore, designers should pay attention to comfort, convenience and safety as well as consumer demand, cost of production, adhere to a human-oriented design concept in line with the law of children's growth to ensure physical and mental health [2].

Clothing's design should meet the requirements for surface coating, lead content limits, testing, certification and labelling requirements. Sustainable design techniques, sustainable or eco-materials and zero-waste techniques are popular in the fashion and clothing industry. Sustainability in clothing design with an extended lifespan is defined as a means of sustainable clothing design that considers multiple functions for greater use with the exception of its aesthetics and basic user safety [3]. Durable multifunctional clothing that allows for experimentation by the wearer may prompt emotional attachment through frequent and prolonged use which decreases the likelihood of discarding the clothing and hence increases sustainability [4]. Therefore, creating multifunctional capsule wardrobe is a possible solution to the problem of excessive clothing consumption in the fast fashion industry as proven by Jalil and Shaharuddin [5].

Multifunctional clothing can be an alternate source of revenue in the fashion industry which supports the movement towards sustainability [6]. Since multifunctional clothing can be repeatedly transformed, its life cycle is prolonged and the utilization rate of the commodity is increased [7]. Furthermore, in this unique design technique, fasteners such as *zippers*, *hooks*, *velcro tape* or *buttons*, whether made sustainable or not, attach individual clothing components. Each component can be unconnected and reconnected to produce a completely different type of clothing at the consumer's whim. Thus, suitable sustainable materials should be strong, soft and compatible with other materials to protect children's health.

Synthetic fibres in children's clothing have a considerable amount of petrochemicals, which impacts the health of children and the environment. Thus, choosing natural fibre over synthetic materials are beneficial in terms of health, sustainability and the environment. Natural fibres are the best choice for children as it is nourishing and healing especially newborns that touch and feel the warmth of the material shortly after birth. Therefore, the clothing should be organic, natural and free from harmful chemicals.

The major benefit of organic cotton is that it is more durable than conventional cotton. It is extremely tear-resistant compared to other types of fabric. For example, organic cotton twill is resistant to wrinkles, creases and shows less dirt and stains [8]. Hence, choosing fabrics made of eco-fibres assist to achieve design purposes in multifunctional children's clothing. This scope has not been studied in previous research and is suggested for more investigation by Cunha and Broega [3].

One of the issues with sustainable clothes especially multifunctional clothing is that there is no clear evidence to indicate clothing production still adversely affects the environment. Most research reported that cotton fabrics are widely used in the children's clothing industry [9-11]. However, Mancini [12] showed that cotton cultivation uses almost 25% of insecticides around the world each year. Jalil and Shaharuddin [5] propound that eco-materials have minimal or zero environmental impact whereby most of which are recyclable. They reported that eco-materials especially recycled fabrics are a solution to increase the clothing life cycle during the design and production phase.

Moreover, the production of organic cotton adheres to demanding requirements and standard. Its content is eco-friendly with minimal health effects. Jin Gam [9] finds that organic cotton fibre as an agricultural crop is produced following strict National Organic Program (NOP) standards without the use of synthetic chemicals such as fertilizers, pesticides and defoliants. Exposing children's skin to harmful chemical substances that can be present in their clothing can cause various health concerns. Hence, it is imperative to use natural fibres such as organic cotton, silk and wool in children's clothing [13].

Furthermore, the demand for eco-friendly natural dye is gradually gaining attention in the international market to save the environment. Ahmed and Elsayed [14] stated that cotton fabrics, especially organic materials, can be dyed in bright shades of several colours that can be available in different weights and designs of woven and knitted fabrics in children's clothing. However, Ismal [15] stated that most of the textiles are dyed and printed using synthetic dyes. The chemical structures and contents of synthetic dyes are frequently questioned and criticized to prevent making phthalates content and other pollutants in textile wastewater. Therefore, ecological natural dyes, without the use of phthalates content and methods arouse interest among researchers, designers, artists and practitioners.

Eco-fibres create eco-materials which Joergens [16] describes as any form of material designed to reduce environmental impact to enhance customer benefit and community health. For example, organic cotton grown without chemical fertilizers and pesticides plays a vital role in the production of a less hazardous environment [17]. Islam [18] investigated the possibility of producing similar or better-quality t-shirt fabrics in terms of physical properties that would be less harmful to the environment compared to other traditional manufacturing processes by selecting organic cotton fabrics and using Remazol dyes. Moreover, Ramasamy [17] showed that knitted fabrics produced from organically grown cotton are superior in performance compared to regular cotton fabrics.

By limiting the use of virgin materials, recycled polyester drastically lowers its environmental impact compared to traditional polyester. Environmental benefits of recycled polyester include a reduced dependency on virgin petroleum as raw material, prevents plastic from ending up in the ocean that harms marine life, decreases greenhouse gas emissions from creating and processing virgin polyester, which can be continuously recycled without quality degradation [19]. Hence, organic cotton fabrics along with sustainable recycled polyester were chosen for this study as the main material to support sustainability.

Studies by the Northern India Textile Research Association (NITRA) have shown that organic cotton fibres have better physical properties than conventional cotton in terms of length, bundle strength, length uniformity and maturity (www.nitratextile.org). The breaking elongation of organic cotton is about 20% higher. The ash and wax content in organic cotton is lower and more absorbent than conventional cotton. Organic cotton shows better durability and colour retention [17]. Morreale [20] investigated that children's wear affects the durability requirements of the product. Since their lifestyles are often active, clothes can become worn out quite quickly, especially after being subjected to stains and soiling. Therefore, children clothes need to be more robust than adult wear and choice of fabric is key. The quality of raw material is pivotal whereby selected fabrics need to demonstrate good tensile resistance in their structure [20].

Abou Nassif [21] investigated the physical properties of micro polyester woven fabrics and found that the increase of weft density of fibres significantly enhances the load-bearing capacity and stiffness. In addition, the increase in wrap density decreases the air permeability and voids leading to an increase in tearing strength. Therefore, polyester fibre elongation enhances which makes it an ideal choice for long usage in clothes. Maatoug [22] investigated the effect of weaving performance on the strength at high pressures for cotton fibres and it was found that less splitting in yarn, resulted in better tensile properties and tolerance under high pressures. On the other hand, lesser weaving performance can be attributed to the poor adhesive and binding force of cotton fibres. In another study done by Reddy and Yang [23], the cotton fibre showed a significant value of tensile strength compared to other types of fibres. Additionally, the elongation of cotton displayed maximum value that makes it an appropriate choice for the clothing industry. However, for higher elongation, the force-elongation curve for cotton was no longer linear as it is softer and more flexible.

Based on the mentioned research, there is no investigation in terms of materials and their mechanical properties applied in multifunctional garments especially children's clothing. Consequently, the authors decided to investigate organic cotton fabrics and recycled polyester in children's multifunctional clothing as being the most sensitive to environmental risks in the clothing industry. It should be noted that previous researchers showed positive feedbacks from parents who purchased such clothes, although the price of organic cotton is higher than the conventional cotton fabrics [24,25]. Therefore, the aim of this study is to test eco-fibres in organic cotton twill and polyester, which are both recyclable properties in the children's clothing industry. The reason for choosing twill fabric is because it is slightly heavier than regular cotton materials with a more structured form for multi-functionality purpose. Subsequently, a mechanical test and scanning electron microscope (SEM) of samples are used to evaluate and observe the material characterization.

2. Experimental

Assessing the intrinsic quality of textiles is one of the principal criteria [26].

Fabric

Samples were made from 100% organic cotton twill woven fabrics with a weight of 160 GSM (7.01 oz yd^{-2}) and a width of 45 inches purchased from fabric.com. The recycled polyester fabric was ordered from www.etsy.com. The characteristics of the fabric were as follows: woven, plain and weight of 150 GSM (grams per square meter).

Scanning electron microscope (sem) and textile tensile test

A study on recyclable material was conducted on the properties such as breaking strength and elongation of 100% organic cotton twill and 100% recycled polyester woven fabrics as the main part of children's clothing by SEM. Textile materials are usually non-conductive, therefore SEM with a low vacuum option is crucial for best imaging [27]. The SEM results demonstrate the microstructure characteristics of textile fibres by observing the structure at the micro-level of the fabric after it has been washed. The fabric samples were then tested for their performance. Indeed, it was used to characterize the surface morphology of the organic cotton and recycled polyester fibers.

This study applied the SEM Hitachi TM4000Plus benchtop model (Figures 1(a) and (b)) to perform the test appearance after dry cleaning or laundering and printing durability as a critical point for multifunctional clothes. The image produced by SEM is through scanning the surface of the specimen using targeted electron beams. Researchers have selected SEM to show the characteristic of the textile fibres because it can observe what happens after laundering at the micro-level structure of the fabric. It can also determine the quality of organic cotton fabrics after four times of regular washing in multifunctional children's clothing [28]. Furthermore, the maximum tensile strength is evaluated when the material is stretched to break by utilizing C224-E057B Autograph AGS-X Series (Figures 2(a)-(f)).

Fibre strength and extensibility are measured during a tensile test in which elongation is applied to a specimen in its axial direction. Constant tension is carried out until the specimen's breaking point. This method is applied to choose a fabric with promising tensile strength in multifunctional clothes, which could also be designed for different functionalities over a long period. The tensile strength of the material samples was performed according to standard test procedure ASTM D5035–11 (2013). Then, the colour fastness wash was tested in the Gyrowash machine according to the ISO-105-CO_3 test method. Other than that, perspiration colour fastness was also tested according to the ISO-105-E04-1994 test method in the perspirometer and lightbox. Finally, the rubbing fastness was tested in a crock meter according to ISO 105 X12-2001 test method.

Pretreatment

In this study, the tensile strength and elongation properties of organic cotton and recycled polyester woven fabrics were determined. All fabric samples were pre-tested following ISO 139 and tested under standard conditions of 20±2°C and 65±4% humidity [29]. Two samples of each fabric have been tested for each set of tests. For each fabric type, four different times of laundering; first, second, fourth and sixth; and drying for each time has been done, considering the weave capability of multifunctional purposes.

Firstly, eight samples including organic cotton (four samples) and recycled polyester (four samples) fabrics were washed as mentioned. One sample of cotton and one of polyester were sent for the SEM test after drying. After one week, six remaining samples of cotton and polyester fabrics were washed. They were sent to be washed again and after drying, one sample of cotton and one of polyester were sent to SEM test. A week later, four remaining samples of cotton and polyester fabrics that had been washed two times previously were washed again and after drying, one sample of cotton and one of polyester was sent to the SEM test. In the final week, the two remaining samples were sent for washing and the SEM test.

Printing

A four-colour process printing directly from a computer file onto a garment was implemented. During the test, digital printing did not encourage the use of phthalates on surface coatings (may be exempted if only CMYK process printing inks were used) (Promotional Products Association International, 2019). Digital printing was carried out by ATLAS Company in Iran, which is certified by the International Standard Organization (ISO). Its digital printing process does not use phthalates contents when printing in colours. Eventually, nine samples of fabrics in size 5 cm × 5 cm were chosen for mechanical testing.

Colour fastness to washing

A fabric that retains its colour during care and use is said to be in a colourfast state. The degree of colour fastness depends on the use of the fabric. IS 687E (1979), which is a measurement test was used to test the fabric for colour fastness to washing. A specimen of 5 cm × 5 cm in size was cut from the fabrics to be tested. A soap solution of about 5 GPL ($g \cdot L^{-1}$) was prepared. Each of the samples was separately soaked in the soap solution for more than half an hour. Following that, the test samples were removed, thoroughly rinsed in cold water, squeezed well and dried. The fabric specimen's colour after testing is compared to a "Grey scale for color change" and a "Grey scale for staining" for most International Organization for Standardization (ISO) colour fastness tests. The Grey scale for color change rates the colour fading of the specimen on a scale from 1 (greatest change) to 5 (no change) (www.iso.org).

Colour fastness to sunlight

Nine sample fabrics were exposed to daylight. The test pieces were evaluated for lightfastness by comparing their change in colour with that of the first sample piece where an opaque cover was placed across the middle of the piece. The first sample piece and nine fabric samples were 5 cm × 5 cm They were assembled and placed onto an exposure rack for daily exposure to the sun from sunrise to sunset until sufficient fading occurred for an adequate comparison. The covers were removed after exposure and the change in colour of the exposed portion of the test piece was compared with the samples. The Grey scale for staining rates the staining of an undyed material tested with the specimen from 1 (greatest colour transfer) to 5 (no colour) (www.iso.org).

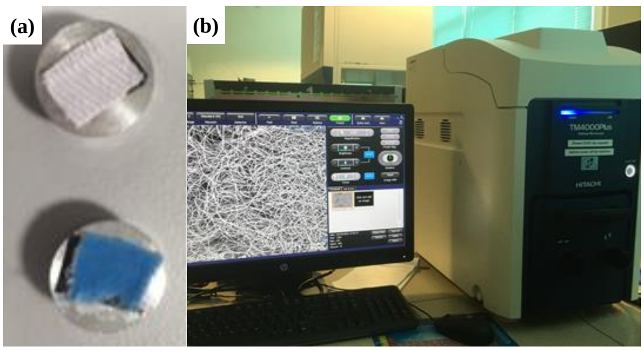

Figure 1. Hitachi TM4000Plus benchtop SEM: (a) cutting of cotton and polyester samples and sticking on the metal, (b) SEM machine set up and extracted micrograph of polyester sample.

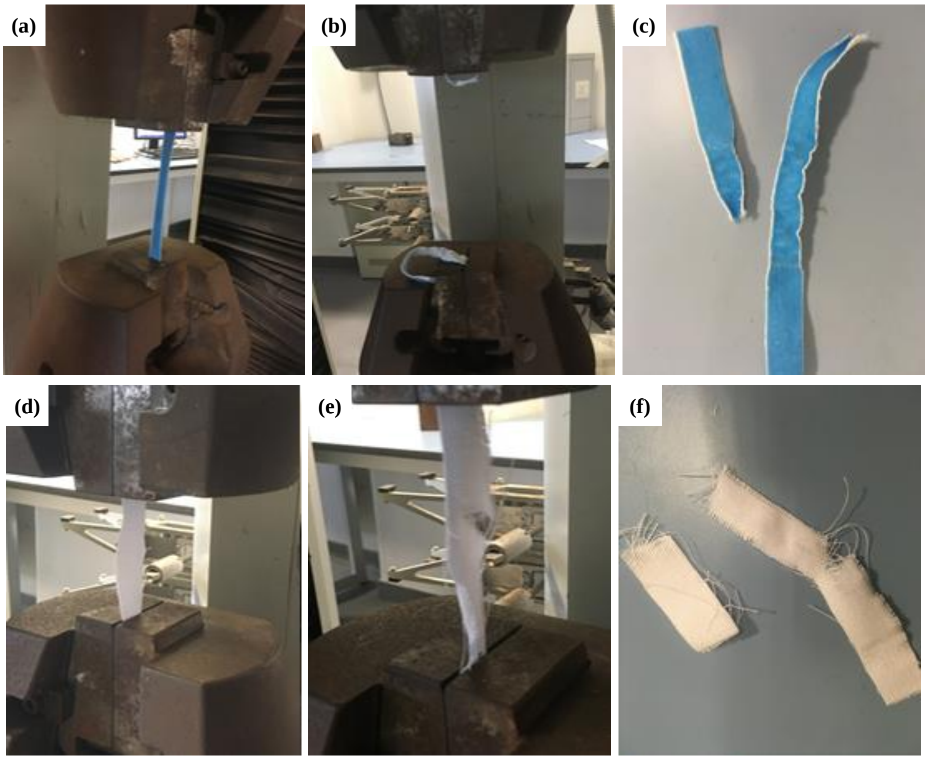

Figure 2. Textile tensile test C224-E057B Autograph AGS-X Series: (a) tensile testing of polyester sample, (b) polyester sample was torn after reaching to its maximum tensile strength, torn polyester sample, (c) tensile testing of organic cotton sample, (d) organic cotton sample was torn after reaching to its maximum tensile strength, (e) torn organic cotton sample, (f) tensile testing of organic cotton sample.

3. Results and discussion

3.1 Mechanical test - appearance after dry cleaning or laundering and print durability colour fastness to washing and sunlight.

Washing fastness was examined in terms of colour changing and staining. The colour change and staining of the sample were assessed in comparison with the greyscale as seen in Table 1. The change in colour of the exposed portion of the test piece was compared with the samples as shown in Table 2. Light fastness, wash fastness, and rub fastness are the main forms of colourfastness that are standardized. The lightfastness of textile dye is categorized from one to eight and the wash fastness from one to five with a higher number indicating better fastness.

SEM analysis was conducted to examine the surface characteristics of the fabrics and their structure. The results showed that the colour fastness properties such as light and washing are good in terms of appearance and structure [20] as shown in 100% organic woven cotton fabric and 100% recycled polyester fabric printed by non-harmful dyes. Next, all nine samples of fabrics were prepared for the SEM test. Figure 2 illustrates the SEM micrographs of cotton and recycled polyester samples at different magnification and from different angles.

Organic cotton after dyeing did not have any change in structure between warps and wefts due to greater resistance strength. Hence, the dyeing process did not affect organic cotton. Moreover, the structures of organic cotton and recycled polyester samples have not changed after four times of laundering due to greater resistance strength. Therefore, choosing organic cotton twill as well as recycled polyester with knitting structure is best to make multifunctional sustainable children's clothing. This is because the results indicated that there were no significant changes in cotton twill and knitted recycled polyester fabrics.

Table 1. Colour fastness to washing.

Sample	After 1st time		After 2nd time		After 4th time		After 6th time	
	Colour change	Staining	Colour change	Staining	Colour change	Staining	Colour change	Staining
Organic cotton	4/5	4/5	4/5	4/5	4	4	4	3/4
Polyester	4/5	4/5	4/5	4/5	4/5	4/5	4	4

Table 2. Colour fastness to light.

Sample	After 1st time	After 2nd time	After 4th time	After 6th time
100% Organic cotton	4/5	4/5	4	3/4
100% Polyester	4/5	4/5	4/5	4

3.2 Mechanical test - tensile strength test

The main reason for testing fibre tensile strength is to evaluate its impact on yarn strength. In yarn structure, fibres contribute to strength through two factors that are inter-fibre friction and fibre tensile strength. The tensile behaviour of cotton fibre and polyester fibre can be determined by testing the reaction of cotton fibre to an axial force.

Organic cotton twill and recycled polyester showed an acceptable tensile strength of fabrics according to Standard Test Method for Breaking Strength and Elongation of Textile Fabrics ASTM D1445/ D1445M-12. It is seen in Figure 3-bottom that recycled polyester fabric sample has considerable high tensile strength as compared to organic cotton fabric sample which is in line with Gizem and Kenan [19]. However, Mahjoub *et al.* [8] found that 100% organic cotton fabric offers less tensile resistance due to the lower strength of cotton fibres. Tensile strength depends mainly on the properties of fibre, yarn and fabric. Fibre, strength and fineness are the factors that determine yarn quality and eventually fabric quality. The maximum force occurs when the textile is torn, which values at 68 N and 144 N in organic cotton and recycled polyester fabrics respectively. The maximum elongation shows 1.75 cm and 5.89 cm in organic cotton and recycled polyester fabrics respectively. Cotton fibres act as groups during processing.

Consequently, mutual interaction between shorter fibres and longer fibres occurs [9]. When fibres are converted into a yarn, the role of fibre assistance becomes even greater, particularly when the yarn is subjected to tensile stresses. The evaluation of strength in terms of tensile properties is considered quite beneficial to most industrial applications [9]. Organic cotton has less crystalline and has more amorphous regions in its structure, which makes it lack strength [27]. In other words, a lesser level of crystallinity and more structurally amorphous region in organic cotton results in strength deficiency. On the contrary, recycled polyester shows high strength as a result of its highly crystalline structure which is in line with the findings Abou Nassif [21].

Additionally, determining the elasticity of fibre is dependent on its exposure to the process of loading and unloading. Elastic fibre exhibits full-dimensional recovery when the load is removed. Cotton fibre exhibits only partial elasticity whereby it is likely suffering some permanent elongation upon loading and unloading. The force-elongation graph of polyester fabric in Figure 3-bottom shows a linear relationship between force and elongation, while cotton fibre does not show the same trend (Figure 3-above) due to the abovementioned reasons which are also in line with the findings by Reddy and Yang [23].

In Figures 4(a)-(i), the morphologies of the sample surfaces were observed by SEM at room temperature. Cotton fibres porous structure makes them an excellent candidate for applications requiring a combination of moisture absorption and wicking when moisture control is needed. Finally, when it comes to toughness, cotton fibres can outperform other fibres in terms of chemical and mechanical resistance. Generally, no significant changes were observed after washing the fabrics under different time frames. It was observed for both cotton and recycled polyester fabrics that the fibres arrangements and the voids among fibres were consistent. It makes these fabrics a suitable choice for making clothes.

The results in Figures 5(a)-(f) show that the structure of warp and weft in organic cotton and recycled polyester fabrics have not been altered significantly after tearing due to the tensile test. The voids are seen in both fabrics. However, debonding and fibre pullout in cotton fibre is more significant than that of recycled polyester. Both types of fabrics keep their original shape and texture after the tensile test. This makes them suitable for children clothing due to their frequent wear. Hence, clothes made of such fibres are not able to break easily and such fibres are resistant under the presence of force.

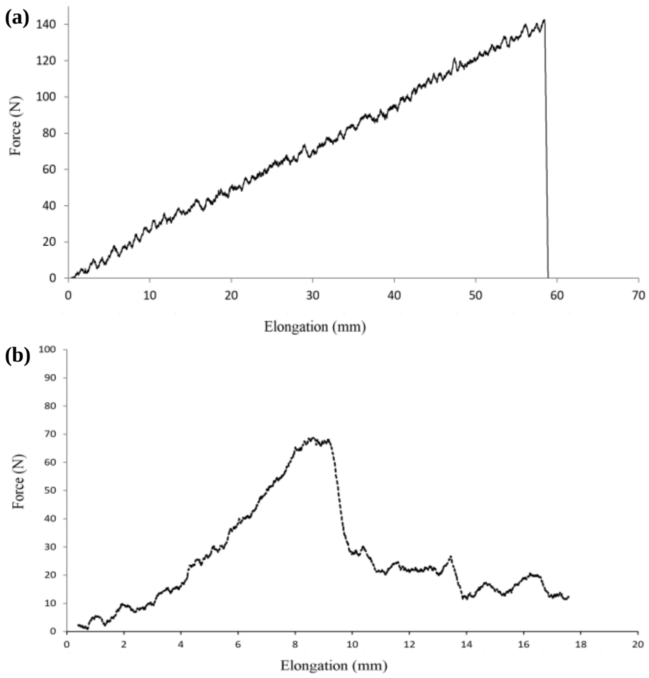

Figure 3. Force-elongation of the organic cotton (above) and polyester fabric (bottom).

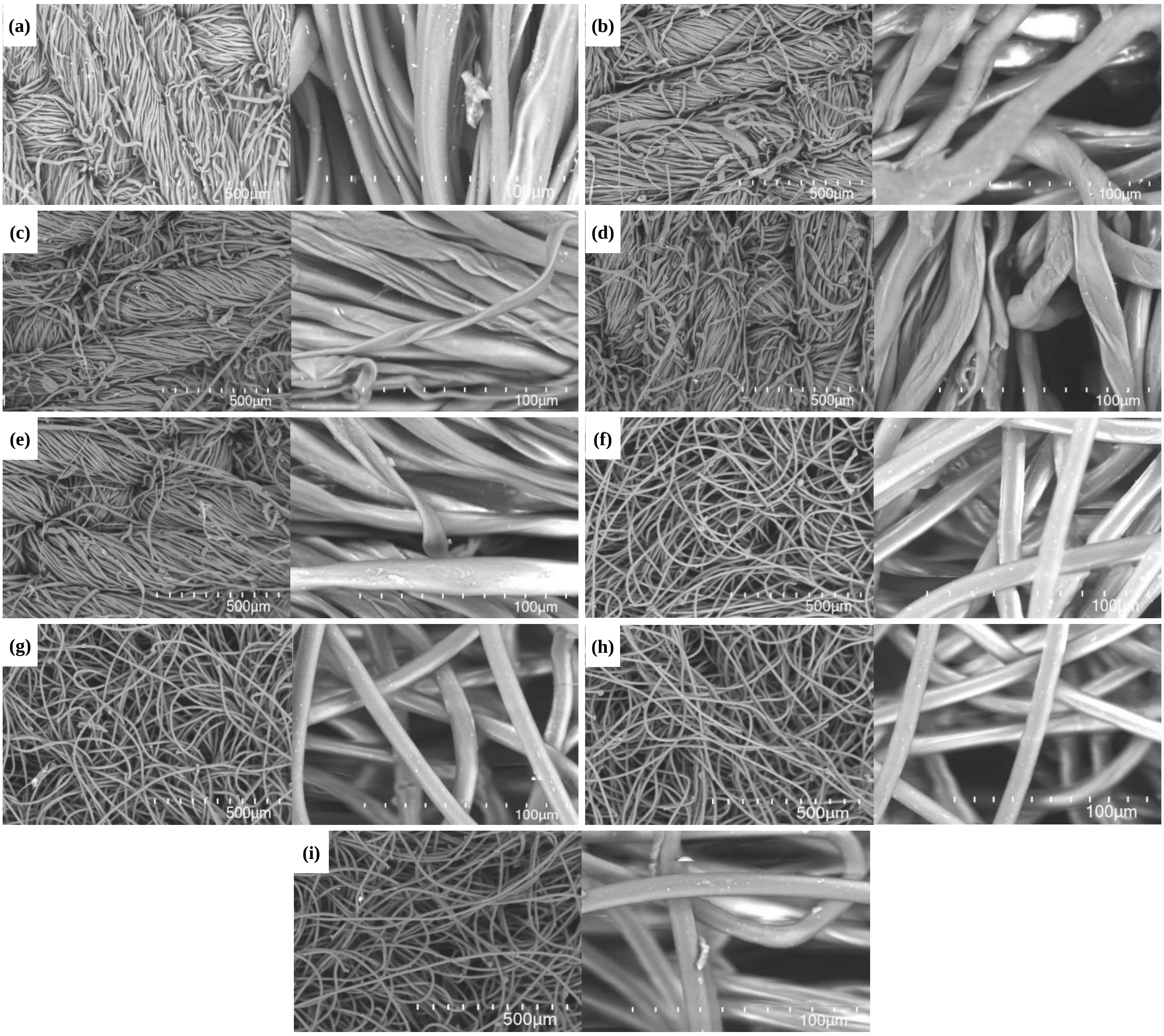

Figure 4. SEM micrograph in 100 µm (left) and 500 µm (right) of (a) none-colour organic cotton, (b) organic cotton after 1st time laundering, (c) organic cotton after 2nd time laundering, (d) organic cotton after 4th time laundering, (e) organic cotton after 6th time laundering; Printed recycled polyester (f) after 1st time laundering, (g) printed recycled polyester after 2nd time laundering, (h) printed recycled polyester after 4th time laundering, (i) printed recycled polyester after 6th time laundering.

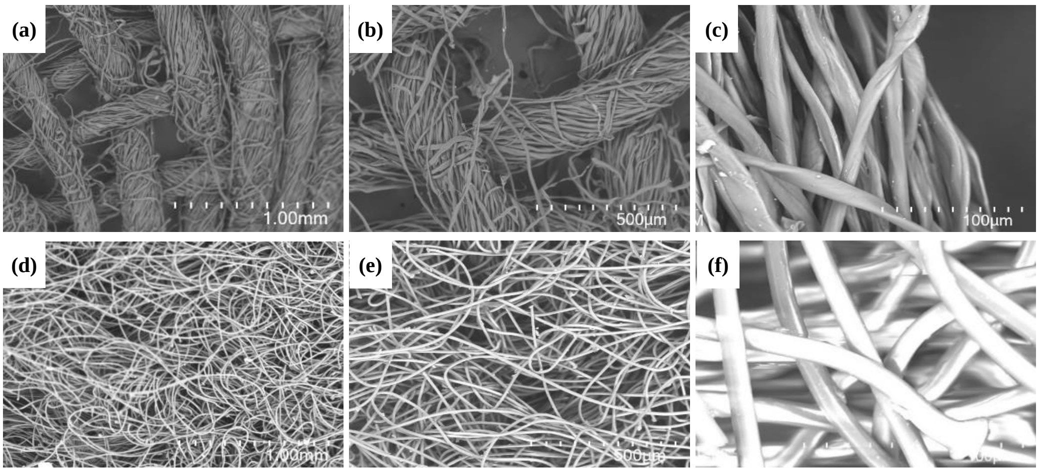

Figure 5. SEM micrographic at different magnification, organic cotton: (a) 1mm, (b) 500 µm, (c) 100µm and recycled polyester (d) 1mm, (e) 500 µm, and (f) 100µm.

4. Conclusions

This paper is an investigation of the physical properties of fabrics made from 100% organic cotton with eco-friendly Remazol series reactive dyeing and 100% recycled polyester printed with disperse dye. An evaluation of cotton fibre and recycled polyester's tensile failure was made using SEM analysis. This evaluation reveals the complexity of the nature of both fabric's failure and stability after laundering periods.

It can be concluded that the selected materials such as organic cotton and recycled polyester are highly suitable for sustainable children's clothing because they possess good tensile resistance and strong structure for multifunctional purposes. Although the strength of organic cotton is not the same as recycled polyester fibre and higher tensile strength were observed for recycled polyester fabric, however other properties are still durable. Hence, these fabrics with such properties can support the multifunctionality of clothing and may lead to an increase in the lifespan of clothes by more than the years estimated. Furthermore, using organic cotton instead of regular cotton would mitigate health hazards caused by growing regular cotton fibres in farming and its use of pesticides.

Moving forward, it is important to manage and focus on the use of organic cotton twill, which increases the fabric breaking strength with only changes in the fineness of the filament while keeping other parameters constant. All in all, the result of this study shows that children's clothing with multifunctional features can be produced using eco-friendly materials such as organic cotton twill and recycled polyester as a solution towards sustainability. Existing studies mostly analyses the intention of the children's clothing design using eco-fibres and more details on developing materials in multifunctional clothes and investigation of technologies in designing could be explored in future research.

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