Towards reinforcement solutions for urban fibre/fabric waste using bio-based biodegradable resins.

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Abstract. The main research question is how to systematically define and characterize urban textile waste and how to effectively utilise it to produce reinforcement(s) with selected bio-based biodegradable resin(s). Several composite samples have been produced utilising predominantly natural and predominantly synthetic fibres by combining loose fibres with PLA, nonwoven fabric with PLA, woven fabric with PLA, two-layer composite & four-layer composite samples. Physio-chemical characterisations according to the established standards have been conducted. The present work is a step toward the circular economy and closing the loop in textile value chain.

1. Introduction
Close loop thinking is an important part of current business strategies to reduce resource consumption and positively contribute to the environment [1]. Consuming resources and generating waste on large scale is typical for mainstream manufacturing industries [2]. ‘Circular economy’ (CE) is an approach that would transform the use of resources in the economy and waste would become a valuable input to other processes and products. Textile industry has huge impact on the environment. Around 90Kton textile waste is collected in the Netherlands. Around 35% thereof is damaged and not re usable anymore as such [3]. Huge amounts of urban waste could serve as raw material sources for the new applications. However, urban waste is less defined and consists of multiple materials. Therefore, the research question in this paper is: how to systematically define and characterize urban textile waste and how to utilise them effectively to produce reinforcement(s) with selected biodegradable bio-based resin(s).

2. Materials and Methods

2.1 Physiochemical Characterisation
Characterisation of the textile fibres/fabric have been conducted to establish the fibre type and percentage of each type in the waste stream. Physiochemical characterisation according to the established standards have been conducted in terms of Raw materials test (AATCC TM 20A-2014), Microscopic images (AATCC TM20-2013), Burn test (AATCC TM20-2013), Moisture regain (AATCC TM 20A-2014), Oil extraction to determine the percentage of oil in the fibres (Mesdan Lab, Code 273B), DuPont Waterdrop test (AATCC TM79-2014) density, fibre/fabric thickness, weight per
m² (ASTM D3776-07), Elongation and tensile strength (ISO 2062:2009). The primary purpose of these characterisation/tests were to identify % of fibres in textile waste streams and suitability of substrates for composite making. Additionally, several synthetic waste streams have been tested with FT-IR (Bruker-Tensor 27) for polymer determination.

2.2 Nonwoven production

In order to understand the effect of dimensional stability of reinforcement on composite making. Some of the loose waste fibres have been converted into non-woven using air-laid web forming and needle punching technique to ensure almost equal strength in all direction. Nonwoven production was carried out at Havivank BV, Tilburg, the Netherlands.

2.3 Composite production

Hot press technique (preheating at 200⁰C for 40min and pressing with 2MPa for 3-5 min) has been used for composite samples using three different poly lactic acid resins (PLA 2003D granulates which is high molecular weight and crystalline, PLA 4060D granulates which is low molecular weight and amorphous and PLA nonwoven with unknown properties) from Rodenburg Biopolymers BV and Havivank BV, The Netherlands. Resulting composite samples have been evaluated using Charpy test (ISO 14125:1998) for toughness/energy uptake and Three-point bending test (ISO 179-1:2010) for the flexural strength.

3. Results and Discussion

3.1 Characterisation of textile waste streams

A systematic approach has been adopted (Figure 1) to handle the textile waste streams. Physicochemical tests and characterisation (see section 2.1) have been conducted to identify the % of certain fibre type in the textile waste stream. As there are hardly no pure waste streams, the textile waste has been broadly categorised as A) Predominantly natural fibres, further divided in to three parts a) recycled fibres; such as Jute, Cacao Jute, Denim, Cotton, Acrylic wool blends, workwear mix fibres, b) dust; such as cotton dust, Acrylic wool dust, and c) woven fabrics; such as jute bags and Denim jeans. For the B) Predominantly synthetic fibres samples are e.g. waste stream 1 (claimed as Polyamide 6/6.6), waste stream 2 (claimed as Polypropylene fibres), waste stream 3 (claimed as Polyethylene) and waste stream 4 (shredded fibres from workwear/uniforms) etc. Considering the complex and heterogeneous mix from batch to batch, the fibre/textiles waste streams have been used as such, since it is almost impossible to purify them into 100% natural fibres and 100% synthetic fibres

Figure 1: A systematic approach to handle fibre/textile waste into composite samples.

Physicochemical characterisation of several textile waste streams (dust, fibres, non-woven, woven) samples have been conducted according to the tests and standards mentioned in the section 2.1. However, it was still not possible to establish the fibre types from the synthetic waste streams. Therefore FT-IR studies of three different synthetic waste streams (WS1, WS2, WS3) have been conducted using similar reference materials. The results of FT-IR spectra are presented in Figure 3.
Figure 2: FT-IR spectra of A) reference Polyamide vs WS1-waste stream 1, B) reference Polypropylene vs WS2 – waste stream 2, and C) reference Polyethylene vs WS3-waste stream 3.
It is clear from the Figure 3A that important absorption peaks of amide (3292 cm\(^{-1}\) and 1631 cm\(^{-1}\)) are not seen, when looking at the waste material of PA 6/66 (WS1). The remarkable peaks in the waste material (WS1) are at 1713 cm\(^{-1}\) and 1235 cm\(^{-1}\). These peaks together are characteristics of an ester group. From comparing the spectra of the waste material, it is clearly not a polyamide. The spectra of WS1 has more similarities with PES, therefore it can be said that the main component of WS1 is polyester and not as proposed polyamide spectra.

Figure 3B shows the comparison FT-IR spectra of reference Polypropylene and waste stream 2. The spectra of the PP reference show three important peaks around 2916 cm\(^{-1}\), 1453 cm\(^{-1}\) and 1375 cm\(^{-1}\). The peaks at 1375 cm\(^{-1}\) and 1453 cm\(^{-1}\), are similar to the absorption frequency of CH\(_2\) bending, these two peaks form an alkane group. It can be said that the main component is a PP of the reference material. It is clear that there are additional peaks at 1713 cm\(^{-1}\) and 1235 cm\(^{-1}\) resembling to polyester (Figure 3B). Hence it can be said that the waste stream 2 is a mixture of PP and PES.

Finally, woven jute bags, loose cacao jute fibres, and cotton mix have been selected for the further study from predominantly natural fibre waste stream. For the synthetic fibres waste stream the chosen materials are waste stream 1 (PES), Waste stream 2 (Polypropylene/PES mix) and Uniforms/Workwear mix. The decision was made on the basic of availability of raw materials and ease/possibility to make in composite.

### 3.2 Predominantly natural fibre based composite production

On the basis of availability of raw materials and possibility to make composite, three different samples have been selected for the further study. The samples are woven jute bags, loose cacao jute fibres, and cotton mix. Composite samples are produced with two-layer and four-layer reinforcement. The idea is to check following two hypotheses, i) if converting loose fibres into non-woven delivers composite with higher strength, ii) if doubling the amount of reinforcement layers leads to double the mechanical strength. The selected results are presented in Figure 3.

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<tbody>
<tr>
<td></td>
<td>Two layers</td>
<td>Four layers</td>
<td>Four layers (Highest bending properties)</td>
<td>Four layers (Highest energy uptake)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Bending modulus (N/mm(^2))</th>
<th>Charpy test strength (in J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite 1</td>
<td>2673</td>
<td>0.39</td>
</tr>
<tr>
<td>Composite 2</td>
<td>3228</td>
<td>0.78</td>
</tr>
<tr>
<td>Composite 3</td>
<td>5680</td>
<td>0.37</td>
</tr>
<tr>
<td>Composite 4</td>
<td>750</td>
<td>1.68</td>
</tr>
</tbody>
</table>

**Figure 3**: Predominantly natural (loose, non-woven and woven) reinforcement samples.
As described earlier, the Three-point bending test (ISO 179-1:2010) is meant for flexural strength and the Charpy test for the toughness/energy uptake. As seen from the figure 3, it is clear that doubling the reinforcement layers (sample 1 vs sample 2), not necessarily doubles the bending modulus, however the energy uptake tends to increase linearly. The higher flexural strength/bending properties (5680 N/mm²) achieved by woven jute bag and PLA as resin. The woven structure of the reinforcement seems to be responsible for this results. The highest toughness/energy uptake (in J) is achieved for prepressed loose denim fibres. This can be attributed to easier penetration of PLA resin across the loose denim fibers during composite production. To sum up it is advisable to use loose fibre reinforcement for rigid surface like tables. Woven reinforced materials such as the jute bag could be used for chairs as their bending behavior is superior. Additionally, it is to say that mixing Jute and Cotton in nonwoven structure (Figure 3, sample 2) could be a good solution for making a product with mixed/moderate properties.

3.3 Predominantly synthetic fibre based composite production
Several composite samples have been produced utilising predominantly synthetic fibres by combining loose fibres with PLA, nonwoven fabric with PLA. Figure 4 shows selected composite samples made out of predominantly synthetic loose fibres vs. non-woven. The hypothesis was that additional dimensional stability of reinforcement would provide more mechanical strength. Results showed that converting the loose fibres into non-woven doesn’t necessarily increase the mechanical strength. This is attributed to the fact that, the melted PLA resin can easily penetrate around loose fibres compare to non-woven reinforcement. The choice of PLA resin certainly showed influence in terms of mechanical strength. Composite (sample C1 = 1.45 J) made with PLA 2003D granules showed higher mechanical strength, attributed to its high molecular weight and crystallinity compared with PLA 4060D (0.25 J) and PLA web (0.31 J). Additionally, samples produced with nonwovens reinforcement gave highest flexibility to polypropylene composite. (2919 N/mm²).

![Figure 4: Predominantly synthetic reinforcement samples (loose vs non-woven).](image-url)
4. Conclusions

During the course of this project, we identified a great number of possible material combinations with varying technical and mechanical characteristics, as well as with a wide range of different perceptive values (all data not shared). With some of the most favourable material combinations first prototypes are developed, tested and investigated. Several loose fibre/non-woven/woven reinforced composite samples have been prepared using three different PLA resins as a matrix for bio-based composites. Composite samples with several interesting combinations with workwear mix fibres, Polypropylene non-woven, Jute fibres, Denim fabric etc., have been produced with diverse properties (strength and flexibility). It is possible to get tailored made end properties in terms of strength, flexibility by selecting right type of reinforcement material and choice of resin. However further systematic research is ongoing in the direction of optimizing end properties and circularity of the composite product(s). There are opportunities in the area of i) large number of end applications, ii) the higher added value on the material properties, iii) large volumes (with use of textile based waste materials) can be achieved with and iv) the ability to optimize for (full) circularity. The present work is a step toward the circular economy and closing the loop in textile value chain.

Acknowledgments

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References


A preliminary study on puncture resistances of top and bottom layers of multi-layered needlepunched nonwoven geotextiles

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Abstract. Needlepunched nonwoven textiles are commonly used as geotextiles for various applications. Considering both environmental and economical benefits, utilization of recycled fibres in nonwoven geotextiles has become an attractive issue. Within this scope, the aim of this study is to evaluate the puncture resistance performances of top and bottom layers of multi-layered needle punched nonwovens made of recycled fibres to be used as membrane protective geotextiles by comparing them with those of made from polypropylene and polyester fibres. Puncture resistance results indicated that nonwovens made of recycled fibres demonstrated good performances at this preliminary stage.

1. Introduction
Geotextiles are defined as permeable fabrics generally obtained through nonwoven technology to be used in association with soil considering their ability to separate, filter, reinforce, drain, or protect. In recent years recycled fibres are commonly used in nonwoven geotextiles for their cost effectiveness and their replaceable strength performances with that of the originals. The assessment of mechanical strength and durability performances of nonwoven geotextiles consisting of original and recycled fibres have attracted great attention from researchers for several applications [1-6]. From this standpoint the aim of this study is to evaluate the convenience of needle punched nonwovens made of recycled fibres to be used as membrane protective geotextiles by comparing their puncture resistance performances with those of made from polypropylene and polyester fibres. The puncture resistance test of the fabrics were carried out according to the test standard TS EN ISO 12236.

2. Materials
Fibre fineness and staple length values of the standard polypropylene fibre and polyester fibre were 6 dtex and 64 mm respectively. Recycled fibres were gained by mechanical recycling of any type of textiles consisting of various fibres with length values in rank of 20 mm-80 mm and fineness values changing between 6-12 dtex.

3. Production Step

3.1 Preparation for needlepunching
Fibers opened up from the bales were applied an antistatic agent to prevent static electric charging and were laid out for 24 hours. Thereafter they were fed into a fan for twice and blown up to the fiber storage area. By this way the fibers were opened and dispersed for the preparation for carding process. In the carding zone fibers passed over 3 pairs of opener and cleaner drums and licked-in to the main carding zone in which they were aligned in an essential parallel direction and carded by 6 pairs of
band type wired carding drums. The web formed by this way on the card was removed from the card by doffer to the cross lapper. Folding of the layers were adjusted to meet the mass per unit area values for each type of fabric and layered form of the webs were delivered to preneedle punching passing through the web feeder.

3.2 Needlepunching Process

Preneedle punching loom used for this research was 12 cm x 240 cm in size and contained approximately 3600 needles vertically arranged. Needle type was 5 x 18 x 32 x 3 ½ R333 G 1002. Production speed was adjusted to 3.67 meters/minute. Considering these production parameters punch densities of the fabrics were calculated through the formula given below where:

\[ \varepsilon = \frac{n}{P/m} \]

- \( \varepsilon \) is punch density (m\(^2\)),
- \( n \) is number of needles in the unit width of needling loom (m\(^{-1}\)).
- \( P \) is production speed (m.min\(^{-1}\))
- \( m \) is number of punches in unit time (min\(^{-1}\)).

Needlepunch densities of the nonwoven fabrics were calculated through this formulation as indicated below and found to be 10.218 punches/m\(^2\) for each type of nonwoven fabric which can be considered as a soft preneedle punching process.

\[ \varepsilon = \frac{1}{\frac{3.6}{3}} = 10218 \text{ punches/m}^2 \]

In the end, 12 types of preneedle punched nonwoven fabrics consisting of three types of raw materials and 4 equivalent masses were produced through a conventional needle punching system. Properties of fabrics which will be used as top and bottom layers of multi-layered end-products are given in Table 1.
Table 1. Nonwoven fabric properties.

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Mass per unit area (g/m²)</th>
<th>Fabric Thickness (mm)</th>
<th>Needlepunch density (punches/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>100</td>
<td>2.592</td>
<td>10218</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>150</td>
<td>3.876</td>
<td>10218</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>200</td>
<td>4.743</td>
<td>10218</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>250</td>
<td>5.337</td>
<td>10218</td>
</tr>
<tr>
<td>Polyester</td>
<td>100</td>
<td>2.482</td>
<td>10218</td>
</tr>
<tr>
<td>Polyester</td>
<td>150</td>
<td>4.260</td>
<td>10218</td>
</tr>
<tr>
<td>Polyester</td>
<td>200</td>
<td>4.456</td>
<td>10218</td>
</tr>
<tr>
<td>Polyester</td>
<td>250</td>
<td>4.750</td>
<td>10218</td>
</tr>
<tr>
<td>Recycled fibre</td>
<td>100</td>
<td>2.128</td>
<td>10218</td>
</tr>
<tr>
<td>Recycled fibre</td>
<td>150</td>
<td>2.927</td>
<td>10218</td>
</tr>
<tr>
<td>Recycled fibre</td>
<td>200</td>
<td>3.580</td>
<td>10218</td>
</tr>
<tr>
<td>Recycled fibre</td>
<td>250</td>
<td>4.170</td>
<td>10218</td>
</tr>
</tbody>
</table>

4. Test Procedure
The determination of puncture resistance performances on nonwoven geotextiles has a great importance to evaluate required features for durability of the products [7]. Test procedure was carried out according to “Geotextiles and geotextile-Related products-Static puncture test” TS EN ISO 12236. Test specimens were prepared through the instructions and conditioned for 24 hours. Five samples were duplicated for determining puncture resistance.

5. Results and Discussion
In the case of soil-geotextile interaction the geotextile is subjected to perpendicular forces to it’s plane due to the subgrade surface irregularities [9]. Therefore researchers have studied puncture resistance performances of needlepunched nonwoven geotextiles by means of differences in testing procedures [9,10]. Puncture resistance values of the fabrics are presented in Table 2. These values are obtained for preneedled top and bottom layers of the multi-layered end-products.

Table 2. Puncture resistance results of fabrics (N).

<table>
<thead>
<tr>
<th>Raw material</th>
<th>100 g/m²</th>
<th>150 g/m²</th>
<th>200 g/m²</th>
<th>250 g/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>1.1076</td>
<td>7.2160</td>
<td>10.0100</td>
<td>17.7375</td>
</tr>
<tr>
<td>Polyester</td>
<td>1.3800</td>
<td>8.0000</td>
<td>12.0800</td>
<td>10.9200</td>
</tr>
</tbody>
</table>

In this study in the case of comparing puncture resistance values from the viewpoint of mass per unit area datum between each raw material group, it is obviously seen that for both PP fabrics and PET fabrics puncture resistances increased with increasing mass per unit area values as presumed excluding the puncture resistance of the PET fabric of 250g/m². Hereby, when needling density is too high for the punched web, the bonding structure of the nonwoven is damaged and the puncture resistance of nonwoven decreases accordingly [11]. Although the thickness values of the PET fabric of 200 and 250
g/m² were very close to each other the aforementioned reason might have caused the puncture resistance result. Considering recycled fabrics it can be observed that except the puncture resistance value of the fabric of 200 g/m² rising values take place for rising mass per unit area values respectively.

In the case of statistically analyzing puncture resistances of the fabrics through SPSS13.0-One way ANOVA, the effect of mass per unit area on puncture resistance values was found to be statistically significant for each type of fabrics as seen in Table 3.

**Table 3.** The analysis of variance table for mass per unit area values of the fabrics

<table>
<thead>
<tr>
<th>Factor</th>
<th>F</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass per unit area</td>
<td>7.772</td>
<td>0.000</td>
</tr>
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</table>

Considering the effect of raw material type on puncture resistance performances of fabrics, it can be stated that the puncture resistance values obtained for PP fabrics were found to be the lowest values for each group of mass per unit area excepting the group of fabrics of 200 and 250g/m². The puncture resistance values of PET fabrics except the fabrics of 200 and 250g/m² can be ranked as the second for each group of mass per unit areas. The puncture resistance values belonging to recycled fabrics were found to be the highest excluding the fabric group of mass per unit area of 200 g/m². Besides, recycled fabrics performed dramatically good puncture resistance values that can be related with the entanglement of longer fibers they involve.

In the case of statistically analyzing puncture resistances of the fabrics through SPSS13.0-One way ANOVA, the effect of raw material type on puncture resistance values was found to be statistically significant for each type of fabrics as seen in Table 4.

**Table 4.** The analysis of variance table for raw material types of the fabrics

<table>
<thead>
<tr>
<th>Factor</th>
<th>F</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>5.248</td>
<td>0.008</td>
</tr>
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In the figure above puncture resistances of each type of fabrics were demonstrated in relation with thickness values. As it can clearly be seen from the table, puncture resistances of fabrics except that of PET 250 g/m² and recycled 200 g/m² increased in relation with the increasing thickness values. Besides, thickness values of the fabrics for each mass per unit area group were in close relationship with each other. Puncture resistance values of recycled nonwoven fabrics outperformed results of the others which might be contributed to the longer fibres they involve concluding in higher entanglement.

6. Conclusion
In this study puncture resistance performances of 12 types of preneedle punched nonwovens in 3 different raw materials and 4 equivalent mass groups were compared considering mass per unit area values and raw material types. When mass per unit area values were taken into account; between each raw material group, it was obviously seen that for both PP fabrics and PET fabrics puncture resistances increased with increasing mass per unit area values as expected excluding the puncture resistance of the PET fabric of 250g/m². Considering recycled fabrics it can be observed that except the puncture resistance value of the fabric of 200 g/m² rising values took place for rising mass per unit area values respectively.

In different raw materials groups, puncture resistance values obtained for PP fabrics were found to be the lowest values for each group of mass per unit area excepting the group of fabrics of 200 and 250g/m². The puncture resistance values of PET fabrics except the fabrics of 200 and 250g/m² came after for each group of mass per unit areas. The puncture resistance of recycled fabrics were the highest excluding the fabric group of mass per unit area of 200 g/m². Besides, recycled fabrics performed dramatically good puncture resistance values that can be related with the entanglement of longer fibers they involve.

Acknowledgments
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References


Social and economic importance of textile reuse and recycling in Brazil

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Abstract. Brazil is an important world producer of textiles. However, this industrial activity, combined with additional import and trade, generates millions of tons of textile scraps, unsold clothing and discarded post-consumption garments. There is a great potential for the recycling and reuse industry in the context of solidarity and circular economy. The present study aimed to present examples in Brazil related to waste reduction, reuse and recycling of textiles in the context of solidarity economy. In this way, some representative initiatives, from Sao Paulo, Minas Gerais and Rio de Janeiro states are presented and discussed based on these principles and approaching responsible lifestyles and environmental awareness and the refusal to waste resources in general. The main socioenvironmental benefits are related to the training of labor and local income generation, the population’s awareness of consumption patterns, saving of natural resources and raw materials, and mitigation of environmental impacts.

Keywords: textile reuse and recycling, solidarity economy, social project, fashion.

1. Introduction

In the process of transformation towards sustainability there is the need to understand the consumption aspect more deeply [1]. Despite the efforts, the general perspective of industrial production in terms of sustainability is worse than ever, mainly due to the increase in production and consumption volumes [2] [3]. The overall volume of textile consumption at the global level is estimated at more than 30 million tons per year and the environmental impacts of this industry are remarkable [4]. Although it is estimated that the consumption of textiles by the population accounts for 5% of the carbon emissions for the total amount of goods acquired by an individual, the purchase of clothes is increasing and the shortening of the useful life of these articles increases the environmental load of the industry [5] [6].

Today, textiles and clothing are much cheaper compared to household income than a few decades ago. These articles had lower prices, causing individuals to have more pieces and of lower quality. In the United Kingdom in 1950, 30% of a family’s income was used to purchase clothes. Currently, this number corresponds to 12%, with a greater number of consumed items. It is also estimated that, progressively, clothing will form a decreasing proportion of total household expenditures due to falling prices and household enrichment [7].

Environmental and ethical issues in the textile and clothing industry are complex, and traditionally they have been viewed through a very limited lens, focusing on “eco-materials” or ethical principles of production, for example. A more holistic approach is needed in this area. Therefore, it is essential to
produce more knowledge not only about materials and production processes, but also about consumer relations with products discarded in the context of sustainable development [2] [3].

Even the reuse of post-consumption clothing is difficult because the huge amount of textile articles. Charity shops get more donations than they can actually manage. Thus, while retail markets are crowded with cheap clothes, second-hand clothing markets are also saturated. In Finland, a second-hand charity shop received more than eight million kilograms of old clothing in 2010, an increase of 3.5% over the previous year [2] [3].

In Brazil, the reuse and recycling of textiles has no due importance, unlike some European countries and the United States [8] [9] [10] [11], where laws on the disposal of solid wastes and studies about industrial and domestic scraps of textiles have relevance. Countries such as China, Bangladesh and India, among others, are major exporters of clothing products, mainly to developed countries of the European Union and the United States, which do not have to deal strongly with the environmental problems arising from industrial textile production, but with the problems related to the disposal of post-consumption.

Brazil, one of the largest textile and confection manufacturer [12] [13] [14] [15] should be more concerned on issues related to leftovers and discards of these two industrial areas as well as post-consumption. In numbers, the country is the 5th world producer of textiles (about 1.8 million tons of articles made per year) [15]. Also, the 7th in the production of yarns and flat fabrics and the 3rd in the production of knitted fabrics [16], in addition to generating millions of direct and indirect jobs. Brazil produces 170,000 tons of textile scraps per year. About 80% of this material is destined to irregular discard and landfills. A waste that could generate income and promote the establishment of sustainable businesses [17].

Only in relation to the disposal of post-consumption garments, near 5.5 billion of pieces per year are produced from 32,000 Brazilian companies, and it is estimated that more than 150 million have no definite destination and end up stockpiled, destroyed or moldy. On average, the collections have sales from 50% to 75%, when exposed in retail. The leftovers go to sales off or bazaars. At the end, the loss can reach 7% not sold, which can be donated, shredded, deposited in landfills or incinerated [18]. Still, in 2011, Brazil had 1,200 industrial companies, exclusively manufacturing professional clothes, with a production of 267 million of uniforms per year. Besides, the country also imports textiles and clothing. These data highlight the potential that this segment can generate for the recycling industry in the context of circular economy [15].

The textile reuse can be done by industrial or artisan ways. The manual process is simple and consists of the reutilization of the fabric scraps to make upcycling or/and handicrafts in an infinity of objects that depend exclusively on the craftsman's abilities and creativity [19].

Including different stakeholders from civil society, such as NGOs - Non-Governmental Organizations, universities and community groups, it is crucial for companies to create recycling and waste recovery strategies through new policies. South America is an example for organizations involved in the construction and adaptation of programs and policies related to solid waste management [20].

The increasing of production and disposal of textile articles is a global fact. Despite the large amount of textile wastes, mainly from the confectionary industry, in Brazil they are still not properly availed and are currently disposed of in landfills. At the same time, in this country there are examples about the concept based on the principles of solidarity economy [21] [22] aiming to valorize and train the involved workers, as well as objectifying waste reduction, reuse and recycling, approaching responsible lifestyles and the refusal to waste resources in general [20].

In this way, the present study aimed to present examples in Brazil related to associations and actions linked to the management activity of textile waste.

2. Methods
The methodology was based in visitations and application of questionnaires and conducting semi-structured interviews with representatives of different agencies and institutions in the Brazilian textile
sector, as well as representatives of associations and cooperatives linked to the management activity of textile waste.

The semi-structured interview favors not only the description of social phenomena, but also their explanation and understanding of their totality, besides maintaining the conscious and active presence of the researcher in the process of collecting information [23] [24].

3. Results

The waste transformation into new products could help to mitigate environmental impacts, but it could also drive income generation for the population and the local creative industry. On the other hand, informal selective collection is quite commonplace. Part of this activity happens in cooperatives or organized associations with or without municipal support. Sometimes these groups add value to the collected materials, which are separated for creating new products. In Brazil, about 800,000 people are involved in the informal work of reuse and recycling of materials, and often also in cooperative recycling. Most of these individuals live in poverty and work in dangerous conditions [22].

Although the activity of selective waste collectors is recognized according to the Brazilian Classification of Occupations, this work remains in the field of informality. Not all cooperatives or associations are formalized and not all have access to labor rights as provided by law. Recently, regional cooperation networks have emerged to promote collective marketing and engage themselves in other collective actions [25].

The resource recovery rate per recycler and cooperative varies according to the quality of separation of materials at source, mode of transport, equipment, infrastructure at the processing center (where separation, baling and storage take place), level of training, among others. On average, a recycler carries up to 200 kilograms of material per day, which amounts to about 4 tonnes per month. The working journey is long, often 12 hours a day, traveling an average distance of 20 km/day on the search for recyclable materials. Informal and organized recyclers are estimated to recover 60% of the paper and paperboard that are recycled in Brazil and up to 90% of all materials that feed the recycling industry in the country. It is still estimated that formal and informal recyclers recover up to 20% of urban solid waste produced in Brazil [26].

The recyclable waste collectors that are integrated into a cooperative or association, and supported by local government, often experience previously unknown opportunities for other workers in this sector. These practices further empower waste collectors and open new ways for social development [27]. In this way, waste collectors contribute to the neighborhood improvement, waste cleaning, demonstrating resource recovery behaviors, and thus create opportunities for greater community cohesion. This detail has been widely observed in the case of Brazil and other countries [28], as also discussed by Zapata-Campos and Zapata [29] for the Nicaragua case.

The National Solid Waste Policy (Brazilian Federal Law 12,305, Aug. 2, 2010) [30] provides guidelines for municipalities to collaborate with solid waste reuse and recycling groups. It supports the participation of waste collectors in actions of shared responsibility for the product life cycle and prioritizes recycling cooperatives in formal recycling programs [30] [31].

In a study published in 2011, about data covering the year 2010, the Brazilian Institute of Geography and Statistics (IBGE) recorded the existence of more than 11,000 non-profit organizations in Brazil, which covers the social development, culture and art, and a total of 507 non-profit organizations exclusively for employment and training activities [32].

In the South and Southeast Brazilian regions, notably in São Paulo state, there are some chemical and mechanical textile waste recycling companies [33] [34] [35]. However closer to the principles of solidarity and circular economy, several institutions and NGOs are already working with the reuse of textile wastes, such as the Ecotece Institute [36] and the Retalhar company [37]. These residues are transformed into corporate gifts, such as cases, ecobags and rubbish bins for cars produced by inclusive labor and resold to the origin companies.
There are numerous initiatives, brands and stylists who work with upcycling in fashion. One of them is the Brazilian brand COMAS, which produces cloths using as main raw material discarded men’s shirts. The products have classic style, simplicity and timeless design (Figure 1a) [38].

![Figure 1. (a) Cloths made from discarded men’s shirts (COMAS, Sao Paulo – Brazil) [38]. (b) “Viver de Costura” social project (“Living Sewing”, Minas Gerais – Brazil) [39]](image)

The “Viver de Costura” (“Living Sewing”) social project (Figure 1b) provides sewing training for women in the Sabara region (state of Minas Gerais). It is linked to the Center for Design and Social Responsibility of Design School (State University of Minas Gerais), and aims, besides to teach sewing, to realize product development with innovative solutions and design. This project was born as part of the ‘Minas Raizes’ mother project, which received the “Citizens without Borders” award in 2011 in the ‘Culture’ category [39].

In the metropolitan area of Rio de Janeiro (“Baixada Fluminense”, Rio de Janeiro State) composed by cities such as Belford Roxo and Duque de Caxias, for example, there is a Local Productive Footwear Arrangement [40]. Despite its enormous economic potential, it is worth mentioning the generation and discarding of the textile scraps from this sector. The work of the Superintendence of Women of the municipality of Belford Roxo, which currently develops the “Feirart de Bel” (“Art Bel Fair”) project, is observed. It brings together at least 30 artisans every week to exhibit and market, in squares, parking lots and malls, the handicraft produced through the reuse of discarded raw materials, among them the textile ones [41].

The EcoModa Project (http://culturaniteroi.com.br/ecocultural/), established in Niteroi city (Rio de Janeiro State) since 2006, reuses textile wastes donated by various companies to create new garments. Based on the principles of solidarity economy, it aims to value and empower the involved workers and students, as well as to reduce waste by reusing and recycling [42]. In this way, it also contributes to debate about the reduction of urban waste, since fashion has been a fundamental tool for dialogue between the State and the socio-cultural foundations [43]. In addition to promoting the culture of sustainability, income generation is one of its goals. Subsequently, the group of graduates can multiply their knowledge in the communities, where they reside, working with the recycling and reuse of materials. The project aims, above all, to formally structure cooperatives with each group of graduate students who will then manage their products/brands independently of the project [43]. In addition to the remarkably social character, it is a laboratory for creations and experimentations in the area of design (Figure 2), besides to give subsidies to its students in the management / pricing of fashion pieces, as well as assists in the final parade of course graduation.
The pieces of EcoModa students have had space in the Brazilian fashion market. In the "Fashion Business", one of the sector’s largest business event, held in late 2015, EcoModa showed the students’ autumn-in-2016 collection produced with banners, hoses, fabric wastes, post-consumption jeans and other materials, which commonly would be discarded. In this same event, renowned Brazilian brands such as Blue Man, Mara Mac, Mary Zaide, Marcos & Rudy, Rosana Bernardes, Totem and Victor Dzenk were also present [43].

The Association of Brazilian Women Entrepreneurs - AMEBRAS (Rio de Janeiro city, RJ) (http://www.amebras.org.br/) carries out reuse activities of textile materials from the Rio carnival, since 1998. It has approximately 886 associates from different classes and business segments, and has professionally qualified about 22,000 people, young people and adults, living in different communities in Rio de Janeiro.

The main raw materials for reuse are fabrics, feathers, feathers, sequins and various trims. They are obtained in the moments known as "dispersion" of the samba schools, that is, when each of them finishes their presentation in “sambadromo da Marques de Sapucai”. During the parade of each school, many items of the floats and samba dancers' costumes fall off to the floor.

AMEBRAS is an official seller of the products of Rio carnival. Some of its products are also marketed by “Camisa de Bamba” (http://www.camisadebamba.com.br/). These are notebooks, calendars, mobile covers, kits with bath towels, slippers, mugs, flags, dolls, among others. Part of these items are industrialized, produced with virgin raw material, approximately 25% of the total. The other 75% of the items, such as headgear, masks, costumes and dolls, are handcrafted with reuse raw materials through the professional training courses that AMEBRAS performs. Moreover, since the ornaments are made with reuse material available at that time, it should be emphasized that there is no way to control the acquired raw material, which can vary (from colors and compositions) from time to time - unlike what happens with the industrialized products and/or produced with virgin raw material, but generating exclusive creations (Figure 3).

Figure 2. Creative process in EcoModa project: (a) discarded clothes as raw material; (b) accessories made of fabrics, purses and bags produced by the students; (c) the designer and stylist Almir França (left) explains the process of construction of the new pieces; (d) detail of the new fabric created through the reused raw materials [Source: Authors’ files].

Figure 3. Examples of costumes and carnival ornaments made with reuse material by AMEBRAS students [Source: Authors’ files].
The brand "Acorda" follows firmly in the initial proposal to create products from discarded fabrics, maintaining the contemporary tendency, but moving in the opposite direction to fast fashion through sustainability and creativity. Each piece is handcrafted by means of an assembly process, where the fabrics and their combinations are highly selected to guarantee exclusive and loving products to their customers [44].

Acorda brand (http://www.useacorda.com/) exists since 2013 and arose from the interest of founders for fashion, carnival and the taste of producing unique pieces. For the summer / 2017 collection titled "Afrofuturism," the brand aims to "tell stories" through their creations. The target audience is composed mostly of Afro culture and history fans and foreigners from different countries who visit Rio de Janeiro. The partners of Acorda are also photographic models in the advertising campaigns of their products because they believe transmit greater visual identification with their target audience. Currently, Acorda has an assortment of products of approximately 270 pieces, among ecobags, clutches, pockets, among others (Figure 2), which are sold on its own site, in fashion fairs and in multi-brand stores.

![Figure 4. (a) The partners Luana Maria (left) and Michelle Andrade (right) pose for the current brand campaign, titled "Little Africa"; Pieces produced by Acorda: (b) ecobags, (c) clutches, (d) and (e) pockets, Source: Acorda [44]](image)

Acorda has a strong concern with environmental and social sustainability. Therefore, it makes commercially fair partnerships with productive groups. The brand uses mainly discarded fabrics as raw material for its creations. It also uses trims from carnival costumes, animal food bags, bank bags and even carpentry waste, all discarded by their sources. Majorly, the material used in the production comes from donations. It seeks to awaken a greater awareness of the individuals in relation to the discards of solid residues. Thus, the creation of the pieces occurs, basically, through the material available for that moment or collection, not being able to choose / define colors or types of fabric, previously.

In addition, it tries to minimize the generation of residues in its production - here understood as the "residues of residues", using, practically, 100% of the material received so as not to generate leftovers. In this way, one must be able to create pieces with all available material and adjust their size to the size of the flaps received as donation.

In all visited institutions, many problems related to management of textile waste were pointed. Among them, the principal are: i) inexistence of legal and / or tax incentives for companies that use reuse raw materials in their production; ii) lack of a well-established network of contacts for the procurement of raw materials; iii) difficulties in transportation of the donated material; iv) mixed composition or/and color/pattern of textile wastes, demanding time-consuming work for the trial and separation; v) hygienization of the donated raw material, since many donated are dirty and require pre-treatment and / or cleaning to be used in the production; vi) space for storage of inputs and consequent increase in the production of pieces.

In the State of Rio de Janeiro and in other Brazilian regions (excepted Sao Paulo State), industries that recycle textile discards have not yet been found, only reuse activities employing this material. In
this way, Local Productive Arrangements can provide actions related to these activities. Reuse of the textile material is performed with discarded material by confections, as well as on articles of clothing discarded by industries and individuals. These residues are often reused in projects and social projects that have a concern with the socio-environmental area, since they aim to train vulnerable workers, generate income and minimize environmental impacts. It is also observed that the reuse of textile waste through public policy or company actions is a fertile field for creative experimentation and production of new fashionable pieces and accessories with sustainable appeal, as well as contributing to the preservation of the environment.

Some projects that reuse textiles or participate indirectly in this activity receive financial assistance in their actions from State or Municipality. However, there is no legal incentive at Federal, State or Municipal level regarding the reuse/recycling of materials by private companies of any segment. In addition, there are problems related to the lack of a Reverse Logistics, as well as onerous transportation, unhygienic raw material, no adequate storage space, and the low number of recycling companies installed in the Brazil. The main socioenvironmental benefits are related to the training of labor and local income generation, the population's awareness of consumption patterns, saving of natural resources and raw materials, and mitigation of environmental impacts.

Thus, although Brazil is on the right way in promoting the recycling and reuse of wastes, including textiles, there is still much to be done in terms of a solidary and circular economy approaches in terms of benefiting the people and the society.

4. Conclusion

Despite of the huge waste of textile residues that could be profitable in a context of circular and solidarity economy in Brazil, several institutions and NGOs are already working with the reuse of textile wastes in order to valorize and train the involved workers, generating income and increasing the environmental awareness. Some of these examples are presented and discussed in this study, in the belief of seeking sustainable alternatives for textile and fashion sectors. Furthermore, textile reuse and recycling activities are a positive contribution to the disposal of solid waste from industries, garments or even domestic waste, given the significant volume of these and also given their incorrect destination, commonly disposed in rivers, bays and landfills.

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Investigation of eco-friendly casein fibre production methods

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Abstract: The growing environmentally awareness of the consumers leads to a lot of new products in the textile industry. Either a sustainably produced textile or one which is created by reuse of a waste product is preferred. One possibility to create fibers from waste is using waste milk for casein fiber production. Opposite to several other biopolymers, however, spinning fibers from casein causes diverse problems. This article gives an overview of the investigations on how to produce fibres from the milk protein casein in a sustainable way, i.e. without formaldehyde or other polluting ingredients. Mechanical properties as well as water-resistance were investigated for chemical and physical modifications of the base composition. In this way, the positive influence of paraffin oil and wax as well as aggregation at high temperatures could be proven, while temperature treatment resulted in a higher E-modulus.

1. Introduction
Approximately 2 million tons of milk are thrown away every year only in Germany. This waste milk still contains 2.8-3.2 % of the protein casein which was already used for fibre production in the 1930s. But at that time casein fibres were produced with formaldehyde, the process needed a lot of water and the production could not be made profitable; a problem which is not yet solved [1]. Over the last years new methods were found to produce these fibres in a more eco-friendly way and a newly developed process without using formaldehyde is described in a recent patent [2]; however, these fibres are co-spun together with viscose or wool. In electrospinning, casein can be used in combination with other materials [3,4] or in graft copolymers [5], again with weak water resistance. On the other hand, casein is able to absorb water which gives a smooth sensation on the skin and makes it comfortable to wear. Especially people with skin diseases such as neurodermatitis would benefit from this clothing. It is also reported that casein has a natural antibacterial effect. Additionally, casein can be used to attract macromolecules (i.e. proteins, polysaccharides, etc.) and to work as a size-selective molecular device [6]. In the form of a multilayer film, it has been reported to promote biomineralization [7]. This opens a wide range of new possibilities in the medical sector. Due to these properties of textiles containing casein, more investigations should be performed to increase strength and water resistance of casein fibers. However, crosslinking with citric acid should be avoided since these fibers are known to be cytotoxic [9].

In previous investigations casein powder was mixed with water in different proportions, stirred, slowly heated up to 75 °C and spun by hand extrusion through nozzles of different diameters as well as used as coatings on different textile fabrics [8]. To reduce brittleness of the resulting fibre, different amounts of glycerine were added to the solution.
This resulted in significantly different viscosities depending on the casein-water proportion. In all cases, the necessity to add the casein to heated water in small amounts during stirring emerged. Independent of the mixing ratio, the resulting fibres or textile coatings were quite hard and brittle. The coated textile fabrics showed a water resistance of up to 33 minutes. To improve the results, another chemical approach was tested in this paper.

2. Materials and Methods

Technical casein from bovine milk containing 90 % protein (Sigma, St. Louis, USA) was ground in a mortar and filtered through a sieve with 200 µm mesh size. Viscous paraffin oil from Roth (Karlsruhe, Germany) and glycerol (99.8 %) from alexmo cosmetics (Weyhe, Germany) were added in most recipes. Partly, glucose or wax (KahlWax 6592, Trittau, Germany) were added. For all compositions, glycerol was mixed with equal amounts of distilled water. Casein was added under stirring at 500 rpm at room temperature. Depending on the recipe, other ingredients were added. The pH value of this mixture was carefully adjusted to pH 6.5, using 0.5 M NaOH since casein is soluble in water only above pH 6.4. After the casein was completely dissolved, the mixture was heated to 65 °C to decrease viscosity and allow formation of fibers through a spinning nozzle.

Table 1 gives an overview of the different recipes under investigation in this study.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Glycerol 50 %</th>
<th>Casein</th>
<th>Paraffin oil</th>
<th>Glucose</th>
<th>Wax</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20 ml</td>
<td>10 g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20 ml</td>
<td>10 g</td>
<td>5 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>20 ml</td>
<td>10 g</td>
<td>2.5 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>20 ml</td>
<td>10 g</td>
<td>1 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>20 ml</td>
<td>10 g</td>
<td>5 ml</td>
<td>10 g</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>15 ml</td>
<td>10 g</td>
<td>5 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>20 ml</td>
<td>10 g</td>
<td></td>
<td></td>
<td>5 g</td>
</tr>
<tr>
<td>8</td>
<td>20 ml</td>
<td>10 g</td>
<td>5 ml</td>
<td>5 g</td>
<td></td>
</tr>
</tbody>
</table>

The produced fibers had diameters of approx. 1 mm, according to the relatively large spinning nozzle which was chosen due to the high viscosity of the spinning solution. Additionally, in this way significant influences of small deviations of the fiber diameter on the tests of mechanical properties and water solubility could be avoided.

All samples were dried in two different ways: placement on a PTFE foil at room temperature, and drying on a PTFE foil during temperature treatment using a heat gun.

Mechanical tests were performed using a Sauter universal test instrument, mounting the casein fibers with a free clamping length of 50 mm and elongating them at a speed of 5 mm/min.

Water resistance tests were carried out by inserting the fibers into water for different times between 0 min and 60 min. The fibers were then dried in an oven for 36 h at a temperature of 65 °C. Comparing their masses before and after the test allowed calculation of their absolute and relative losses of mass, respectively. The tests were performed 3 times per fiber.

3. Results and Discussion

Figure 1 depicts exemplary results of investigations of the mechanical properties of casein fibers, produced according to Table 1 and dried at room temperature or during heating, respectively. Generally, there is a tendency towards higher elongation for the fibers dried at room temperature, while the highest breaking forces are reached for the hot dried fibers no. 2 and no. 7, prepared with the highest amount of paraffin oil and wax, respectively.

Compared with other casein fiber investigations, the tensile strength of the fibers produced here is approx. one order of magnitude lower. This may be attributed to small air bubbles which are visible in
all fiber cross-sections. Apparently, in a next step, the amount of air in the spinning solution must be reduced, e.g. by using ultrasonic degassing after heating or by stirring in vacuum.

In the tests depicted here, the main focus was not on high breaking forces, which are not necessary for diverse applications in the medical sector. More important is the possibility to tailor the water solubility, especially for drug release or similar medical applications.

Figure 2 depicts the results of the respective tests. Here, especially the results of the longest immersion time show differences between the different chemical compositions of the samples and the temperature treatment during drying. Relatively low mass losses were reached for sample 2 as well as sample 7 after hot drying. Apparently, wax as well as paraffin oil support water resistance, while glucose – which was reported by another group to help crosslinking [10] – does not show any effect on the water resistance of the gained fibers.

Although the results depicted here are not yet sufficient for an application of casein in most medical applications, the experiments show that increasing water resistance of casein is also possible without adding citric acid.

4. Conclusion
To conclude, we have investigated the influence of different chemical ingredients and temperature treatment on casein fiber production. The mechanical properties are significantly lower than in other biopolymers which are in the order of a few cN/dtex, i.e. a few hundred MPa [11], but one order of
magnitude higher than foams from microcrystalline chitosan [12], suggesting their use in medical applications which do not necessitate high mechanical strength, e.g. in wound healing, drug delivery or for tissue engineering. Chemical modifications as well as temperature treatment resulted in significantly increased water resistance, showing a way to possible eco-friendly production methods of casein fibres without formaldehyde or cytotoxic citric acid.

References
Application of recycled fibres and geotextiles for the stabilisation of steep slopes

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Abstract. The recycled fibres and textiles were used for the protection of the steep slope exposed to intensive rill erosion. One part of the slope was protected with the geotextiles formed from the meandrically arranged thick ropes containing a nonwoven manufactured from a blend of recycled natural and synthetic fibres. For the protection of the other part, the recycled polyester fibres mixed with the covering soil were applied. After the installation, the behaviour of the slope was monitored and the efficiency of both techniques was compared. It was stated that both, the geotextiles and the loose fibres randomly distributed on the soil prevent washing away the soil particles and protect the slope from sliding. It was revealed that the recycled fibres can be satisfactory utilized for the efficient protection of the slope against erosion and sliding.

1. Introduction

Construction of earth structures and exploitation of open mines lead to the formation of slopes prone to land sliding and endangered by surface erosion caused by water. Due to the high risk of landslide and erosive damage, the protection of the slopes to ensure their stability is highly desirable. Different methods are used for the stabilization of the slopes. One of the techniques, often applied for several decades, involves the application of the geosynthetics. Geosynthetics have high biological and chemical resistance, non-corrosiveness, lightness and relatively low price. They are usually supplied as rolled products which can be easily transported and spread on the slopes. The installation of the geosynthetics is easy and does not require a lot of manpower or the use of heavy, specialized equipment. The installed geosynthetics provide an aesthetic look of the protected objects [1-3].

Different products including geotextiles, geomatts, geogrids and geomembranes are offered on the market. The variety of available products allows the selection of products most suitable for the local circumstances.

In addition to the known products which have been used for many years, new geotextiles were invented few years ago. The innovative geotextiles were built from meandrically arranged thick ropes which were connected into segments with additional linking chains. The geotextiles were successfully used for the stabilization of the slopes prone to land sliding in the gravel pit and disused lignite mine, as well as for the protection of the drainage and road side ditches [4-7].
For the manufacturing of the ropes, the Kemafil technology and various materials (easily available on the local market) were used [5]. It was revealed that the pre-consumer or post-consumer textile wastes can serve as a valuable raw material for the manufacturing the geotextiles. The production of geotextiles extends the life of the fibres and is an interesting alternative to troublesome methods of waste textiles disposal.

The second technique for the stabilization of slopes consists in reinforcing the soil with randomly distributed natural or synthetic fibres. The fibres mixed with the soil serve as natural plant roots, which improve the strength of the soil and the stability of natural slopes. The technique was used for various civil engineering structures such as pavement layers, retaining walls, railway embankments, as well as for the protection of slopes, foundation engineering and anti-earthquake geo-structures [8].

The reinforced soil mixture sprayed onto the eroded, cut slopes can be used as an infilling of the erosion gullies. This can be an effective repair method, especially in low cohesion materials like sand, dispersive clays or soils containing gypsum [9]. The impressive example for the implementation of this technique was the use of the polypropylene fibres for the stabilisation of a huge embankment constructed of residual fat clays in Texas [10]. During the investigations, both of the above mentioned techniques were used for the protection of the steep slope exposed to intensive rill erosion. The efficiency of each method and their combination in the protection of the slope was analysed.

2. Materials and methods

2.1. Site characteristics

The investigations were performed in a terrain located in the foothills of the mountain range Beskid Maly, in the northeast suburbs of Bielsko-Biała (Poland). The area is formed by meadows spread on the wide and gently sloping northbound hills.

In order to start an economic activity on the hill, three flat terraces were artificially formed (Fig.1a). In this way, steep slopes were generated between terraces. The slopes had the length of 5.5 m and the inclination of 1:1.5. On the slopes three types of soils were identified. The upper part of the slopes is a backfill and is formed from clay of intermediate plasticity (CI) with water content $w = 18.4\%$, liquid limit $w_L = 38.2\%$, plastic limit $w_P = 16.7\%$ and plasticity index $IP = 21.5\%$. In the middle part of the slope, there is the clay of low plasticity (CL) with $w = 20.4\%$, $w_L = 34.7\%$, $w_P = 16.9\%$ ($IP = 17.8\%$) and in the lower part of the slope, the gravelly clay (CG) with $w = 20.4\%$, $w_L = 45.1\%$, $w_P = 20.8\%$ ($IP = 24.3\%$) were stated.

![Figure 1](image_url)

**Figure 1.** The experimental site in the suburbs of Bielsko-Biała: a/ overall view; b/ rill erosion on the surface of the slope
The slopes were exposed to the intensive rill erosion caused by the streams of water flowing from the one to the next terraces (Fig.1b). For investigation purposes, experimental plots with a width of 2 m were separated on the slope (Fig.2). Four plots were protected with the geotextiles built from the segments of ropes arranged in a meander-like pattern. Three of them were covered with the soil mixed with different amounts of polyester fibres. As a reference, one plot was covered by the soil without fibres. Similarly, three plots not protected with the geotextiles were covered with the soil mixture with the polyester fibres and one plot was covered with the soil without fibres.

![Figure 2. Schematic layout of the experimental plots.](image)

### 2.2. Materials

For the manufacturing of the geotextiles, waste strips of the nonwoven from recycled fibres supplied by Amanda (Bielsko-Biala, Poland) were used. The nonwoven was made from blended recycled natural and synthetic fibres obtained by shredding of the post-consumer textile wastes. The nonwoven was produced by means of the stitch-bonding Maliwatt technique. The web of the recycled fibres were stitched by the polyester multifilament thread with a linear mass density of 148 dtex. The parameters of the nonwoven are presented in Table 1.

<p>| Table 1. Parameters of the nonwoven used for the production of the ropes |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|</p>
<table>
<thead>
<tr>
<th>Thickness [mm]</th>
<th>Mass [g/m²]</th>
<th>Tenacity [kN/m]</th>
<th>Elongation at break [%]</th>
<th>Static puncture resistance [kN]</th>
<th>Dynamic puncture resistance [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>warp</td>
<td>weft</td>
<td>warp</td>
<td>weft</td>
<td>warp</td>
<td>weft</td>
</tr>
<tr>
<td>3.0</td>
<td>265</td>
<td>3.3</td>
<td>0.9</td>
<td>29</td>
<td>34</td>
</tr>
</tbody>
</table>

The strips of the nonwoven were bounded into thick ropes sheathed by the polypropylene twine by means of the Kemafil technology (Fig.3). The ropes with the diameter of 100 mm were arranged in the meandrical pattern. The subsequent turns of the meandrically arranged ropes were connected with the regularly spaced five chains into segments with the lengths of 6 m and the width of 2 m. To form the chains, the polypropylene three-wire twine from fibrillated fibres with the linear density of 310 dtex was used.
2.3. Measuring methods
The basic parameters of the nonwoven: thickness and mass per square meter were measured in accordance with the PN-EN ISO 9863-1:2016-09 and PN-EN ISO 9864: 2007 standards. For the measurements, the thickness gauge for geotextiles D-2000-G2 (SCHMIDT Instruments, Germany) was used. Additionally, the mechanical parameters of the nonwoven were determined. The measurements of the tensile strength and elongation at break were carried out in accordance with the Polish standard PN-EN ISO 10319:2010 by means of KS50 Hounsfield tensile machine. The static puncture resistance was determined by CBR test, in accordance with the Polish standard PN-EN ISO 12236:2006. The dynamic puncture resistance was measured by cone drop test, in accordance with the Polish standard PN-EN ISO 13433:2006. The parameters of the polyester fibres: length and linear density were determined in accordance with the standards PN-ISO 137:2000 and PN-ISO 6989:2000. Water content, liquid and plastic limits of soils were determined in accordance with the British standard [11-12]. In order to determine the liquid limit, the Casagrande apparatus method (four-point method) was applied.

3. Results
3.1. Installation of the geotextiles on the slope
On the plots protected with the geotextiles, the segments built from the meandrically arranged ropes were spread on the slope, anchored in the crown and fastened to the surface with the steel "U-shaped" pins (Fig.4). The pins were hand-hammered to a depth of approximately 40 cm. After the installation, the protected plots, as well as the plots without the geotextiles, were covered with the 20 cm layer of the soil mixed with the polyester fibres. The mixtures of the soil and fibres, with fibres accounting for 0.25%, 0.5% and 1% of the dry soil weight, were prepared. The mixtures were prepared by spreading the right amount of fibres on the soil layer and then covering them with the additional layer of the soil. For mixing, a road recycler machine was used (Fig.5a). The mixed soil was transferred to the slope and evenly distributed on its surface. Finally, the covering layer was...
compacted by the excavator bucket (Fig.5b). Few days after the installation, the grass seeds were sown on the surface of the slope.

Figure 4. Installation of the meandrical geotextiles: a/ the segments spread on the surface of the slope; b/ fastening of the ropes

Figure 5. Covering of the slope with a layer of the soil mixed with polyester fibres: a/ mixing of the fibres with the soil; b/ formation of the covering layer on the slope

3.2. Monitoring of the slope
In first week after the installation, it was stated that the geotextiles installed on the slope as well as the fibres mixed the soil provide immediate protection of the slope against erosion. During the first rains that fell before grass seeds germination, no erosive grooves on the surface of the slope were detected. In the first period of exploitation, the settlement of the soil located between the turns of the ropes was observed on the plots protected with the geotextiles. Simultaneously, the ropes arranged laterally on the slope formed a network of micro-dams which slowed down the runoff of water. The dams stopped the soil particles detached from the surface and their transport down the slope with the water stream was impeded.
On the plots reinforced with the fibres randomly distributed in the soil, the fibres formed a structural mesh, which held the soil particles. Moreover, the fibres absorbed certain part of energy from the rain drops or flowing water, thus, preventing the washing away of the soil particles.

In the following months the monitoring of the slope will be continued. The influence of the installed geotextiles on the greening of the slope will be evaluated. Simultaneously, the effect of the fibre concentration on the stabilization of the slope will be discerned.

4. Conclusions

The meandrical geotextiles made from the recycled fibres provide efficient protection of the slope against erosion. The subsequent turns of the ropes prevent the soil from sliding down the slope and form bag-like structures which can keep large amounts of the topsoil on the slope, even in humid conditions. The fibres mixed with the clay soil considerably improve the strength of the soils and prevent slope sliding.

The fibres and the geotextiles ensure the protection of the slope immediately after the installation, before the greening of the slope and the development of grass cover.

For the protection of the slope, the recycled polyester fibres as well as nonwoven made from the recycled fibres can be utilized. The use of the recycled fibres in the protection of slopes can contribute to the rational textile waste management.

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References

Textile Sustainability: reuse of clean waste from the textile and apparel industry

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Abstract. Today societies are already experiencing changes in their production systems and even consumption in order to guarantee the survival and well-being of future generations. This fact emerges from the need to adopt a more sustainable posture in both people's daily lives and productive systems. Within this context, textile sustainability emerges as the object of study of this work whose aim is to analyse which sustainability dimensions are being prioritized by the clean waste management systems of the textile and garment industry’s. This article aims to analyse solutions that are being proposed by sustainable creative business models in the reuse of discarded fabrics by the textile industry. Search also through a qualitative research by a case study (the Reuse Fabric Bank) understand the benefits generated by the re-use in environmental, economic, social and ways to add value.

1. Introduction
The exaggerated consumption and incorrect waste disposal have generated increasing and alarming environmental, social and economic problems. Data from the UN (2015) show that carbon dioxide emissions have increased almost 50% since 1990 and 40% of the oceans are impacted by the waste pollution with reduced fishing and loss of coastal habitats. While 1.3 billion tons of food is wasted daily, the vast majority of the world’s people starve in developing countries, where 12.9% of the population is starving. UN projections for 2050 come up with a population of 9.6 million people, requiring 3 planets to provide natural resources to support current lifestyles [1].

Given this context, sustainability presents itself as a way to minimize environmental and social crises in view of the maintenance and perpetuation of resources for future generations. However, there is a strong awareness of society when it comes to rethinking their consumption habits and promoting radical changes in the way they produce, consume and their lifestyles [2].

In this context of transition to sustainability, we can observe the mobilization of some sectors, namely the fashion industry, which begins to point out some proposals for changes in their production systems. In face of the textile and clothing industry’s negative impact in the environmental and social spheres, innovative initiatives are emerging, which seek solutions through systems development built under the pillars of sustainability.

This article presents the main objective of analysing the sustainable dimensions that are being prioritized by organizations related to the textile industry in Brazil, which carry out changes through innovative systems for sustainability. In order to carry out the present study, textile and clothing were delimited, selecting sustainable projects in Brazilian institutions that perform the clean waste management service of the textile and clothing industry for new products development with added
value. The Reuse Fabric Bank of São Paulo was used as a case study and analysed its systemic structure. The tool SDO-Sustainability Design Orientation Toolkit was applied in order to map thru radars the sustainability dimensions, which are being prioritized by the Reuse Fabric Bank, but also applied as systemic innovation strategies.

2. State of Art

2.1 Sustainable Fashion

The fashion industry products have an ephemeral life cycle, as they are mostly designed by trends that stimulate consumers to renew their goods every season and, thus, strengthen the capitalist system structure. In search of systems construction, which oppose the dictates of the fast fashion model, understood as a practice of fashion companies and distribution networks, which focus on the strategy of constantly design updating of their products combined with low production costs, fast flow and low sales prices [4]; also the ones that think more ethically about fashion and generate positive impacts in the environmental, social and cultural spheres with economic equilibrium. Thus, there is an increasing number of initiatives that reflect the sustainable fashion concept. The sustainability process drives changes in the fashion industry, which discusses ways to reduce the clothing environmental impact, exalting the role of designers as systemic change facilitators [5].

Designing for sustainability is about developing products with low environmental impact and high social quality, analysing the criteria, methods and investments of Life Cycle Design. This requires the designer to increase his attention to all phases of the product life cycle, from the raw material extraction stage, in order to product materials, to the final phase of use, which needs to be considered as early as the beginning of the project, named stage of its decomposition or discard [6]. Faced with the possibilities of sustainable actions in the fashion industry, there is a moment of change of scenery, in which a new and more selective consumer emerges, aware of the impact that their actions may have on current generations and their descendants. The consumer also demands brands that are aligned with the principles of transforming the world into a better place [7].

2.2 Sustainable waste management systems of Brazilian textile and clothing industry

The implementation of more effective laws, that charge corporate responsibility for environmental and social issues, has led to restructuring of the textile and clothing industry production chain, not only to comply with the requirements of these regulations, but also with the objective of fulfilling the demands of a growing market, which starts to adopt a more conscious consumption. Under this approach, innovative actions, although still incipient, are being identified. These are redesigning the productive structure regarding the textile and garment industry waste’s reuse with reverse logistics practices and cleaner production. The actors involved in this context change are private companies, nongovernmental organizations, public agencies, community associations, class institutions (trade unions, professional associations, etc.), academia and consumers themselves, who seek alternative and innovative solutions. However, the challenge of balancing production and consumption patterns is still a complex task, aggravated by the fact that sustainability is still a concept in evolution, also by the difficulties in its practical implementation [8].

To make a better comprehension, the actions that are being developed in the Brazilian context, and in order to deepen the knowledge about the sustainable systems construction of the textile and clothing chain, we mapped sustainable initiatives examples, that have been practiced by differentiated actors of this productive chain, as shown below.

2.2.1 Project of Fashion Retail

The "Retail Fashion" project is held in Bom-Retiro - São-Paulo through a partnership between Sinditêxtil-SP (Union of Spinning and Weaving Industries of the State of São Paulo, BR) with the support of ABIT (Brazilian Textile Industry Association and São Paulo City Hall), as well as other institutions in an area that concentrates more than 1200 clothing factories. These generate approximately 12 tons of textile waste (clean waste) per day, which represents 2 % of the annual wastage generated in Brazil [9].
The project, which is still in its initial stages, aims to manage the commercialization of this waste in order to contribute to the reuse of it as raw material for the textile companies and to propose a waste management plan in accordance with the National Solid Waste Policy. In order to avoided that the industry not to be subject to compulsory regulations [10].

2.2.2 The Brandili Textile Brand
The Brandili Têxtil brand has been working in the area of children’s clothing for over 50 years and, for the past five years, it has taken a sustainable stance by using natural resources responsibly. The company, based in the state of Santa-Catarina, reuses textile waste for ecological yarns production. This process relies on a partnership of companies that provide raw material, (cline industrial waste), for reuse in the ecological yarns production, from textile materials and bottles made of polyethylene terephthalate (known as PET bottles). Reverse logistics actions are observed in the company, since the post-consumer distribution channels are formed by reverse products’ flow and materials from products’ disposal, once their original functionality has been exhausted, returning to the production cycle in another way [11].

2.2.3 The Insecta Shoes Brand
The Insecta Shoes brand was created in Porto-Alegre – Rio-Grande-do-Sul in 2014, is distinguished by marking vegan footwear with a positioning that works with animal protection values, since it does not use any animal input in its products. The brand adopts a sustainable posture, because all of its footwear is made of used clothing or leftover fabrics, industrial rubber waste or recycled plastic. All the material is carefully searched in second hand articles fairs, as well as in products of the Reusable Fabric Bank of São Paulo, case study object of this work. In a research carried out in Porto-Alegre, with Bárbara Mattivy, founding partner of the brand, it is observed that there is a concern in extending fabric’s life and, at the same time, guaranteeing a reduction of materials in the production line [12].

2.2.4 The Ecosimple Brand
Created in 2010 in the city of Americana – São-Paulo, the merger result of other textile companies with a business model, added to an innovative and sustainable concept. The fabrics and brand products use 100% recycled materials, combining technology with sustainability. The raw materials used are recycled PES from bottles, discarded clothing or fabric’s leftovers from garment factories and waste from spinning processes that give rise to more sustainable products which are used in a wide variety of segments. Ecosimple presents itself in the Brazilian textile context as a company that uses innovation by adopting a production model that minimizes environmental impact and favour’s poor communities.

2.2.5 Bank of Clothing from Caxias-do-Sul
The Clothing Bank of Caxias-do-Sul (BVCS), in Rio-Grande-do-Sul, was founded in October 2009 as a centralizing body for textile waste from the industries of the Rio-Grande-do-Sul state region. The BVCS receives the waste from the industries, performs a sorting by types of materials and organizes the fabric’s leftovers for posterior assignment to registered communities, which will reuse these materials. What cannot be reused by the communities goes to other industries that make reuse for stuffing or is destined for co-processing, closing the product cycle.

3. Methodology
The research method used was the case study, in order to investigate in greater depth a contemporary phenomenon, in this case, the phenomenon of sustainability in the textile sector. Since it was a technically singular situation, an analysis unit was used, defined by the business model criterion, which performs the collection service, separation and commercialization/disposal of the leftovers from the textile and garment industry, which would have landfills or other destinations that could have a negative impact on the environment and society.

The unit that served as the study analysis object was the Reuse Fabric Bank of São-Paulo capital, which will be explained later. In the second phase of the empirical work development, after categorizing the data, the information was submitted to a tool called Sustainability Design-Orienting
Toolkit (SDO), which aims at guiding the design process for the sustainable systems solution. It is an open-source software with a copyleft license, also it has the option to be used online (www.sdo-lens.polimi.it) or downloaded and installed on a local internet network (LAN) [2]. The tool is originally structured based on three dimensions of sustainability: (1) the environmental dimension; (2) the socio-ethical dimension and (3) the economic and political dimension. For each of the three proposed sustainability dimensions, requirements are used to evaluate a given system and to guide the design process [2]. For each criterion, the SDO system sets a project priority level to A (High), M (Medium), B (Low), or N (Not applicable). The definition of the priority level is set by the user (in this case by the researchers of this investigation).

4. Results and Discussion

4.1 Case Study - Reuse Fabric Bank of São Paulo
The Reusable Fabric Bank structure of São Paulo (BTR) was created in January 2015 with the objective of extending the life of stopped fabrics, stockpiles, clothes cuts leftovers or small rolls of fabric and scraps; also enabling them to circulate again, extending its life cycle through new uses, preventing it from ending up in landfills. The fabrics to be reused are taken to the units and are organized and sanitized. After this process, they are put up for sale, and marketed per kilo to the current value of R$ 45. In case of the user deposits fabrics in the Bank, he will receive credits for each kilo deposited and later with these credits can take new fabrics. The store’s inventory capacity is 1.3 tons and this stock has already been renewed about 4 times, so it is estimated that more than 5 tons of fabric have already been reused in just one operation year of the business. Currently, Reuse Fabric Bank operates with more than 200 users (account holders) who simultaneously deposit and take fabrics. The users’ profiles are small artisans, young designers, renowned stylists, companies that make a more personalized work with the fabrics and even brands recognized for sustainable jobs. All fabrics deposited have the origin registry that allow their life cycle mapping, which guarantee to be a reuse part, certified by a label of guarantee created by BRT (figure 1).

4.2 Application Tool SDO - Sustainability Design Orienting Toolkit

4.2.1 Environmental Sustainability Radar
The diagram of Figure 2 shows the environmental dimension radar of the Reuse Fabric Bank (BTR); the analysis process result of the system’s environmental priority for each criterion established by SDO.

Figure 1: Reuse Fabric Seal given by BTR. Source: website BTR

Figure 2: BTR- environmental dimension radar. Source: www.sdo-lens.polimi.it
The visualization shows that the BTR system has a medium environmental priority when it comes to the issues related to the waste’s transportation and distribution since it does not have the responsibility of collecting the waste. Another point of medium priority is related to the consumption of non-renewable energies; also the item "No Toxicity" does not apply to the system under study, because it does not use fabrics with toxic substances. However, there is a high priority of the system regarding its optimization and concern to both the minimization and to valorisation of the wastes. This awareness is conveyed to all partners and valued in all BTR actions.

4.2.2 Socio-ethical Sustainability Radar
The diagram of the **Figure 3** refers to the socio-ethical dimension analysis result, in which five items with high priority in the BTR system are observed. It is worth mentioning: (1) Working Conditions, (2) promotion of Equity and Justice, (3) promotion of Responsible Consumption, (4) Integration of Marginalized Persons and (5) In function of this system, guarantee great visibility to the actions practiced by the different actors of its structure.

4.2.3 Economic Sustainability Radar
The diagram presented in **Figure 4** shows that three of the analysed requirements were evaluated as being of high priority: (1) Profitability, (2) Added Value for the customer and (3) Partnerships/Cooperation. The other three were categorized as medium, namely market position and competitiveness, long-term business development and macro-economic threats, as it is a business model with little time existence and, mainly, because it is inserted in a market that is experiencing a serious financial crisis.

5. Final considerations
The application of the SDO - Sustainability Design Orienting Toolkit, designed to support the planning and management of eco-efficient systems, allows to analyse the priorities within each sustainability dimension, thus achieving a mapping of the process. In the case of Reuse Fabric Bank, a relative balance was observed in the three dimensions of sustainability under analysis, although a weakness in the macroeconomic context was observed.

The BTR has a strong inclination to value the environmental and social dimensions. The strong partnerships network, established by the Bank (BTR), reinforces the idea of the need for cohesion between different partners that, despite having different specific objectives, are united in a cooperative work. On the other hand, there is still a small fragility in relation to the economic dimension. That is due, because the BTR is involved and facing a national economic crisis context. It still has no...
solutions to take advantage of the system’s full potential. However, it applies efficient techniques aiming at guaranteeing the maintenance of its structure, and despite being a recent business model, already presents evidence of its eco-efficiency.

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Nonwoven production from agricultural okra wastes and investigation of their thermal conductivities

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Abstract. Nowadays bio-based composite materials have been used in rising amounts and demanded widely in industrial uses, as they provide cost reduction and weight loss in the end use products. Agricultural cellulose based wastes can be a good alternative to synthetic fibers and can be used in natural fiber reinforced composite production, as there is a huge (more than 40 million tons) potential for natural cellulose production from agricultural wastes. Okra is one of the most grown vegetables around the world with stems left on the fields after harvest. When the similarity of mechanical properties of okra fibers with traditional bast fibers (flax, kenaf, hemp) are considered, from an economical and an environmental point of view this research emphasizes the potential of agricultural biomass for natural fiber production. In this study, okra stem wastes used for natural cellulosic fiber production and treated with 10% NaOH at 60°C for 10, 20, 30 and 40 minutes. By alkali treatment, decrease in fiber diameter and weight, and increase in tensile strength and elongation % have been observed. Nonwoven production has been done from both the fibers with and without surface treatments. Thermal conductivity properties of both nonwovens have been investigated.

1. Introduction

The importance of studying on bio-based products increased due to rapid consuming of natural sources around the world and increasing environmental problems in the global scale. 50-65 million tons [1] plant wastes are coming out every year in Turkey. Most of them are not utilized and creating additional costs for collecting and destroying, and they are not converted to an economic value.

Okra is an agricultural plant that is easy and effortless to cultivate due to drought-tolerant formation and low water requirements. However, research and studies on the assessment of agricultural stem wastes have begun for the last fifty years [2] and studies on the fiber extraction from them have been done in the last decade [3]. Okra fibers are obtained from the stem wastes remaining on the fields after harvest of okra plants (Abelmoschus esculentus) from the family Malvaceae (Malvaceae). Okra stem waste fibers contain 67.5% a-cellulose, 15.4% hemicellulose, 7.1% lignin, 3.4% pectin, 3.9% fat and waxes and 2.7% water-soluble ingredients [3].

Plant fibers are natural, recyclable, renewable, degradable and sustainable materials. However, since they are hydrophilic materials, they can easily absorb moisture and this is an undesirable
characteristic as it will cause decay. Surface modification is made to facilitate the industrial use of plant fibers and thus to increase it. The surface modification made as a pre-treatment can be applied by many methods to improve the mechanical properties of the fibers, such as strength, and to increase the absorbency of the subsequent treatments by providing surface roughness, some of which are alkalization with sodium hydroxide (NaOH) [4–12] or Sodium sulphate (NaSO4) [12,13], bleaching with Sodium hypochlorite (NaClO) or Sodium chloride (NaClO2) [4,5,8,14], and acetylation with acetic acid [13–15]. Surface modification processes also remove as much of the structural material as lignin, hemicellulose, and pectin, allowing more reaction zones to occur in the cellulosic structure [13]. It has been observed that when the concentration of the chemical substance is too high, as well as being an important factor, it negatively affects the mechanical properties such as the strength of the fiber [12]. When pre-treated with alkaline, the content of cellulose increases to 75–80% due to removal of hemicellulose, lignin, pectin and other water-soluble substances in the okra stem fiber. The fiber becomes less dense and less rigid, which allows for more ability to the fibrillar structure to settle in the direction of tension [16]. The most common and widely used chemical in alakalisation is sodium hydroxide. Alkalisation process changes the natural structure of cellulose from cellulose I to cellulose II, the alkalisation depolymerizes the molecular structure of natural cellulose I by forming short crystals [17].

As 36,000 tons/year okra grown in Turkey [1], utilization of the okra stem wastes has been studied according to 9th developments plan and region development visions of the State Planning Organization, while okra fibers have similar mechanical properties with the traditional fibers [3–5,14,18]. The aim of this study was utilizing the okra stem wastes and contributing them to the environmental biomass cycle by removing the wastes in their sources and by producing environmentally friendly, value added, a novel fiber/product. And it has the leading potential of production of the first fiber/product manufacturing from the agricultural wastes in Turkey.

In this study, okra stem wastes used for natural cellulosic fiber production and treated with 10% NaOH at 60°C for 10, 20, 30 and 40 minutes. By alkali treatment, decrease in fiber diameter and weight, and increase in tensile strength and elongation% have been observed. Nonwoven production has been done from both the fibers with and without surface treatments. Thermal conductivity properties of both nonwovens have been investigated.

2. Materials and Method

Okra stem wastes have been collected from Mediterranean region. Fibers produced from okra stem wastes by using the specially designed machine (100 kg/hour capacity) in Marmara University. The fibers are left in the water-filled containers for 20 days so that the residues on the fibers separated from the plant extracts and the adhesive materials can be removed completely. In order to clean and fibrillate the surface of the fiber samples (each 2 g), surface modification has been applied with 10% NaOH at 60°C in ratio of 1:20 g/ml for 10, 20, 30 and 40 minutes by referring Islam and Pickering’s studies [17]. Then fibers first washed warm at 25°C, were neutralized with 5% acetic acid solution for 5 minutes and dried in the stove at 100°C for 2 hours. Finally, the fibers were conditioned in laboratory conditions (65±2% relative humidity 20±2°C).

Tensile strength and elongation% values of okra fibers have been tested with INSTRON 4411 testing machine (50 N load, 10 mm/min speed) according to ASTM D 3822 standards, their diameters have been measured with Projectina CH-9495 microscope, and their morphological views have been taken with JEOL JSM-T330 electron microscope in Physical Test Laboratory of Marmara University Faculty of Technology Textile Engineering Department. Then combing and needle punching processes have been applied to the fibers with and without surface modifications at the laboratory based sampling nonwoven production line in ITA Laboratories in Istanbul/Turkey for forming nonwoven surfaces. In this line there are combing machine (CFS1/Feeding width-exit 1000 mm, 650m/min.), cross laying machine (FRT50, input-output 1000 mm, band 49 m/min, exit 6m/min.), needling
machine ((MAG4000 roller AR95, preneedling–end needling 1200 mm, distance of the calenders 0-10 mm, roller: 1200 mm, needling speed 0-rpm–400rpm; oven 0-6.5 m/min., roller 0-10 m/min.) that can work separately. The capacity of the machine is 50 kg/h and its width is 1000 mm (Cormatex S.R.L.). Thermal conductivity properties of both nonwovens have been investigated according to TS ISO 5085 standards in Marmara University laboratories with P.A. HILTON LTD.H940 testing machine.

3. Results

The fibers obtained from okra body wastes are amorphous due to their lignocellulosic properties and their most important ingredients are cellulose, hemicellulose and lignin. The characteristic properties of each component play a decisive role in all properties of the fiber. Okra body waste fibers are adhered to each other by materials such as lignin, gum and wax in the cells of the structure. After the fibers are separated from the plant extracts, it is necessary to apply the hydrophilization process in order to remove the water repellent substances like lignin. For this reason, in this study one of the methods used for surface modification to hydrophilize and fibrillate the okra stem waste fibers is the conventional method.

Factors affecting alkalization are the type and concentration of the chemical substances, the duration of the process and the heat. Alkali treatment removes lignin and hemicellulose from the fiber structure. By the alkali processes applied in this project, alkali-sensitive (OH) groups between the molecules reacted with water molecules as shown in equation (1) below to remove the H-bonds, so the amorphous structure and the amount of fibrillation which increases the amount of contact between the fiber and the matrix increased. The surface irregularity also increased with the rupture of the H-bonds, which leads to better mechanical bonding between the fiber and the matrix and to the tensile strength of the composite [19].

\[
\text{Fiber – OH} + \text{NaOH} \rightarrow \text{Fiber – O} – \text{Na} + \text{H}_2\text{O}
\]  

(1)

The stem diameter of the okra plant which grows in different regions in Turkey varies between 10-50 mm. Physical diameters (μm) (figure 1) of okra stem waste fibers obtained from different regions were determined for treated and untreated fibers.

![Figure 1. Diameters of okra fiber samples pre-treated with 10% sodium hydroxide.](image1)

![Figure 2. Measured weights and weight loss % of okra stem waste fibers treated with 10% sodium hydroxide.](image2)

In this study, the diameter of the okra stem fibers was measured from different points of the fiber and the average was taken. As shown in table 1, surface modified fibers showed some swelling due to mercerization and widening in cross-section. However, hemicellulose, lignin and other impurities are also removed during the surface modification process, and accordingly the diameter is reduced to some extent. When the cross-sectional and longitudinal views (figure 3) and diameter measurements of the okra stem fibers are examined, it is seen that there is a linear deformation [5] in the okra stem fibers as well as in all of the plant fibers.
Figure 3. Longitudinal and cross-sectional SEM images of untreated and 10% sodium hydroxide treated okra stem waste fibers respectively.

It is seen that the results of the treatments with sodium hydroxide in the SEM images of okra stem fibers are effective. Inorganic materials, oils and waxes and non-cellulosic materials have been removed from the fiber surface. The chemical modification of the fiber surface appears to modify the surface of the fibers to give rise to roughness on the surfaces. As can be seen from SEM micrographs, it has been found that the conventional method is used to produce fibrillation on the surface of the okra stem waste fibers without damaging the molecular structure of the fiber and reducing its mechanical properties [20]. Because swelling is a physicochemical phenomenon of plant fibers in the context of water and chemicals, water molecules penetrate the gaps in the fiber and open hydrogen bonds, making the cellulosic fibers suitable for swelling. During the swelling process, the hydrogen bonds of the cellulose molecules break off and the water molecules are transported through hydrogen bonds. Thus, the water molecules bond with the OH groups of the cellulose fibers via hydrogen bonds, and as a result, the cellulose fibers begin to swell. It has been found that the degree of swelling is dependent on the number of free hydroxyl (OH-) groups in the fiber [21,22].

Tensile strength, elongation (%), Young's modulus (%) of okra stem waste fibers after surface modification with conventional method are given in figure 4. Its morphological structure, crystallinity, amorphous region ratio and orientation, physical and chemical properties affect the mechanical properties of lignocellulosic fibers. The moisture absorption capacity of lignocellulosic fibers varies depending on the fiber structure. Surface modification processes increase the roughness rate on the fiber surface and the ability to absorb moisture [23].

Figure 4. Mechanical properties of okra stem waste fibers treated with 10% sodium hydroxide.

Figure 5. The calculated heat transfer coefficients of okra fiber nonwovens treated with 10% NaOH at different durations

As shown in figure 4, the increase in the tensile strength of the okra fibers with respect to the untreated fiber in the surface modification with sodium hydroxide according to the conventional method was determined, but decrease at tensile strength over 30 minutes was observed. After surface treatment, the okra stem waste fibers are weighed with a precision scale after preconditioning in lab conditions. The
weight of each sample before treatment is 2 g. The weight loss of the fibers is calculated as a percentage by the following equation (2).

\[
W_j = \left( \frac{W_{\text{before}} - W_{\text{after}}}{W_{\text{before}}} \right) \times 100
\]

(2)\[W_j\]: Weight loss\%, \[W_{\text{before}}\]: Weight before treatment, \[W_{\text{after}}\]: Weight after treatment

Figure 2 shows the weight measurements and the weight loss (%) values of okra stem waste fibers after the treatment according to the pre-treatment. It can be said that 20 minutes of treatment with sodium hydroxide gives very good results and also allows the removal of the most purities. In addition, improvement in the brightness and stiffness of the okra stem waste fibers was observed.

After non-woven surface formation by needle punching method from treated and untreated okra waste fibers, the heat conductivity tests of these nonwovens have been done according to TS ISO 5085 standards. The heat transfer coefficient (K) of non-woven surfaces was shown in w/m °C. The linear conduction module was used in the heat transfer device. The heat flow value (Q) from the digital display of the device was determined in watts. The heat transfer coefficient was calculated by using the eauqtion (3) as shown below.

\[
K = \frac{(Q.d_x)}{(A.\Delta T)}
\]

(3)\[K\]: heat transfer coefficient, \[d_x\]: thickness of nonwoven surfaces, \[A\]: area of test area, \[\Delta T\]: temperature difference, \[Q\]: heat flow value

The heat transfer coefficient K is determined at w/m °C. The \[d_x\] thickness parameter in the equation has a very decisive role. To measure the heat transfer coefficient of non-woven surfaces obtained from the okra stem waste fibers, a material \[\Delta x\] with a diameter of 25 mm have been placed between the two brass plates at the T3 and T4 temperatures. The one side of the nonwoven surfaces have been adjusted to the temperature T3 and the other side of the surfaces to the temperature T4. According to Fourier Heat Conduction Law, while a heat transfer was occurring between the two media with temperature differences from the hot region to the cold region, the non-woven surfaces between these two-media had a certain heat transfer coefficient. According to the Fourier Law, the heat transfer coefficient of the material has been calculated with the equation (4) as shown below.

\[
Q_x = - k.A.(\Delta T/\Delta x)
\]

(4)\[Q_x\]: heat flow value, \[k\]: linear conduction module

After the measurement system started to function, temperatures T3 and T4 have been read from the digital display in every 10 minutes. The heat transfer coefficient of the surfaces has been calculated from the Fourier Law in the direction of the heat energy supplied to the system, sample thickness and area information.

As shown in figure 5, the okra fiber nonwoven treated with 10% NaOH at 10 minutes has the best heat transfer coefficient. Although the okra fiber nonwovens treated with 10% NaOH at 20, 30 and 40 minutes have better heat transfer coefficients than the okra fiber nonwoven which was produced from untreated fibers, their heat transfer coefficients are lower than the okra fiber nonwoven treated with 10% NaOH at 10 minutes. Also, it is seen from the graphic that there is no correlation with the heat transfer coefficients and the treatment durations.

4. Conclusion

Agricultural waste fibers and nonwovens obtained these fibers can have good mechanical properties and thermal conductivity values as the traditional fibers (both natural and synthetic) used in industry. Agricultural waste fibers are cost effective, lightweight, environmentally friendly, renewable, recyclable and degradable. As this study is a part of a TUBITAK (The Scientific and Technological Research Council of Turkey) research project, our studies are continuing. Nonwoven productions from okra stem waste fibers treated with different chemicals and enzymes will be done, and their heat
transfer coefficients will be measured and compared.

Acknowledgements
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References


Silk industry and carbon footprint mitigation

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Abstract. Currently there is a concern with issues related to sustainability and more conscious consumption habits. The carbon footprint measures the total amount of greenhouse gas (GHG) emissions produced directly and indirectly by human activities and is usually expressed in tonnes of carbon dioxide (CO₂) equivalents. The present study takes into account data collected in scientific literature regarding the carbon footprint, garments produced with silk fiber and the role of mulberry as a CO₂ mitigation tool. There is an indication of a positive correlation between silk garments and carbon footprint mitigation when computed the cultivation of mulberry trees in this calculation. A field of them mitigates CO₂ equivalents in a proportion of 735 times the weight of the produced silk fiber by the mulberry cultivated area. At the same time, additional researches are needed in order to identify and evaluate methods to advertise this positive correlation in order to contribute to a more sustainable fashion industry.

Keywords: Silk industry, Carbon Footprint, Sustainability.

1. Introduction
Carbon footprint is the term used to evaluate the total emission of greenhouse gases (GHG) by human activities [1]. It refers to the mass of GHG emitted due to the production, use and discard of a product [2]. Carbon footprint is a simplified form of calculating the environmental footprint of the product, and is based on ISO14040, the global standard for life cycle assessment (LCA) [3].

According to the World Wildlife Fund, carbon footprint of mankind is the main cause of climate change. However, its reduction is an essential step towards ending ecological abuse and live within the limits and means provided by our planet [4]. Companies are now improving communication with consumers, showing a desire to reduce GHG emissions along the value chain. The fashion industry also should provide sustainable alternatives and raise awareness of environmental problems [5] [6] [2].
The sericulture is an agroindustrial activity that comprises three phases: the agricultural cultivation of mulberry (Morus sp.), which is the essential food for the development of the silkworm (Bombyx mori), the zootechnical insect and industrial processing of cocoons for silk reeling [7].
More than 98% of gross silk production of Bombyx mori occurs in China and India; other smaller-scale producing countries are: Uzbekistan, Thailand, Brazil, among others [8]. Brazil is the only producer of commercial-scale silk yarn in the West [9]. Sericulture is an important agroindustrial activity in Brazil, which contributes substantially to the rural economy. The activity is developed mainly in small rural properties, where family labor predominates, representing an important alternative for the improvement of the income and contributing significantly to the decrease of the rural exodus [10].

The sericulture in Brazil is carried out by 2,080 rural families. The total area cultivated with mulberry in 2015 was 4,338 hectares, making possible the production of 2,836 tons of fresh cocoons [11]. Mulberry is used in silkworm feeding. The plantation is easy to cultivate and presents excellent development [12]. Carbon footprint mitigation is done by actions that sequester CO₂ from the atmosphere, reducing the GHG effect. A study conducted in 2014 demonstrated that mulberry trees have a high capacity for carbon mitigation [13].

2. Clothing production and the carbon footprint

The textile and clothing industry is one of the largest and most polluting in the world. This sector accounts for between 2 and 10% of the environmental impact of the European LCA, reaching the categories of products that cause the greatest environmental impact [1] [6] [14]. Waste & Resources Action Program (WRAP) is an UK organization, which works with companies to help them to reduce waste and develop sustainable products. A study presented by it, demonstrates an analysis of the carbon footprint in UK, over a period of one year. The study includes the impacts associated with the amount of clothing that is produced, consumed and disposed of each year [15]. The LCA of a product involves quantifying the impact of a product, considering the different phases of the product life cycle [16]. The carbon footprint, from fiber production to the end of life for each fiber, was measured. The CO₂ equivalent is the result of the multiplication of tonnes of GHG emitted by their global warming potential. Table 1 shows the carbon footprint (kg CO₂e) per metric ton (tonne or 1,000 kg) of the most employed textile fibers [15].

Table 1. Carbon footprint (kg CO₂e) per tonne on all clothing in use in the UK in 2009.

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Fiber Production</th>
<th>Yarn Production</th>
<th>Fabric Production</th>
<th>Garment Production</th>
<th>Distribution</th>
<th>Retail</th>
<th>Use - washing</th>
<th>Use - drying</th>
<th>Use - ironing</th>
<th>End of life</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>1,755</td>
<td>7,961</td>
<td>13,710</td>
<td>668</td>
<td>1,540</td>
<td>462</td>
<td>2,317</td>
<td>1,531</td>
<td>98</td>
<td>-2,362</td>
<td>27,680</td>
</tr>
<tr>
<td>Wool</td>
<td>20,790</td>
<td>8,654</td>
<td>14,316</td>
<td>655</td>
<td>1,516</td>
<td>462</td>
<td>2,317</td>
<td>1,531</td>
<td>98</td>
<td>-4,055</td>
<td>46,284</td>
</tr>
<tr>
<td>Silk</td>
<td>2,031</td>
<td>6,964</td>
<td>12,168</td>
<td>657</td>
<td>1,354</td>
<td>462</td>
<td>2,317</td>
<td>1,531</td>
<td>98</td>
<td>-2,157</td>
<td>25,425</td>
</tr>
<tr>
<td>Flax/linen</td>
<td>335</td>
<td>3,353</td>
<td>5,760</td>
<td>642</td>
<td>1,709</td>
<td>462</td>
<td>2,317</td>
<td>1,531</td>
<td>98</td>
<td>-1,209</td>
<td>14,998</td>
</tr>
<tr>
<td>Viscose</td>
<td>2,118</td>
<td>18,540</td>
<td>5,196</td>
<td>642</td>
<td>1,709</td>
<td>462</td>
<td>2,317</td>
<td>1,531</td>
<td>98</td>
<td>-2,473</td>
<td>30,140</td>
</tr>
<tr>
<td>Polyester</td>
<td>5,357</td>
<td>2,700</td>
<td>8,185</td>
<td>642</td>
<td>1,709</td>
<td>462</td>
<td>2,317</td>
<td>1,531</td>
<td>98</td>
<td>-1,671</td>
<td>21,330</td>
</tr>
<tr>
<td>Acrylic</td>
<td>7,577</td>
<td>18,551</td>
<td>8,768</td>
<td>642</td>
<td>1,709</td>
<td>462</td>
<td>2,317</td>
<td>1,531</td>
<td>98</td>
<td>-3,227</td>
<td>38,428</td>
</tr>
<tr>
<td>Polyamide</td>
<td>8,070</td>
<td>2,700</td>
<td>8,768</td>
<td>642</td>
<td>1,709</td>
<td>462</td>
<td>2,317</td>
<td>1,531</td>
<td>98</td>
<td>-1,946</td>
<td>24,351</td>
</tr>
<tr>
<td>Polyurethane/polypropylene</td>
<td>3,097</td>
<td>2,700</td>
<td>8,768</td>
<td>642</td>
<td>1,709</td>
<td>462</td>
<td>2,317</td>
<td>1,531</td>
<td>98</td>
<td>-1,532</td>
<td>19,792</td>
</tr>
</tbody>
</table>

Source: WRAP [15]

According to the comparative study carried out by WRAP, the Carbon Footprint is 25,425 kg of CO₂ equivalent per tonne of silk fiber produced from the production of cocoons to the end of life. This value, which did not take into account the carbon mitigation made by mulberry trees, this is similar or superior to the other ones from some synthetic fibers [15]. A study by Astudillo et al. [17], which did not take into
account the carbon mitigation made by mulberry trees, also points out to the fact that the environmental impact of silk in mass is remarkably higher than some other fibers. However, it should be noted that silk has very different mechanical properties from other natural textiles and there is no fiber to replace it, being much more valuable as fiber and final textile product.

3. Silk in Brazil
Sericulture was developed in Brazil during World War II, due to the closure of Asian and European ports, a fact that led the United States to import silk from Brazil, boosting its growth [18]. Later, after the World War II, and introduction of the synthetic fibers in the market, there was a crisis in the Brazilian sericulture. Of the more than 40 silk plants that existed, only one is currently in operation in Brazil [19].

Currently, there is only on silk plant in Brazil, the BRATAK. This company is 100 % Brazilian and works in an integrated system with the rural producers. 90 % of its production is exported. The company employs about 2,000 direct employees in its factories and 2,500 families from integrated farmers [9] [20] [21].

One favorable points of the activity are the low initial investment in machinery and equipment, family labor and monthly income, allowing to the producer to manage the cash flow interacting with other activities. In addition, the integration with the company provides safety for the market of cocoons [22].

4. The role of agriculture in climate change
Biomass burning began with the beginning of agriculture about 8 to 10 millenniums ago with the cultivation of rice fields [23]. One of the environmental consequences of cutting and burning the forests for agriculture is the loss of carbon from the forest system, which in turn contributes to atmospheric change and impacts on global climates [24].

One third of all carbon dioxide emissions come from changes in land use. Approximately two thirds of methane and most of the emissions of nitrous oxide come from agriculture. Meanwhile, agriculture offers options to reduce and minimize GHG emissions. One of them is to reduce emission and to minimize the production of atmospheric CO₂, CH₄ and N₂O. The second option is to sequester systematically carbon dioxide in soils and plant biomass [13].

Increasing long-term carbon sequestration in soils and plants will benefit the environment and agriculture. The direct sequestration of carbon in the plant occurs when the plants photosynthesize the atmospheric CO₂ in the plant biomass. Consequently, part of this plant biomass is indirectly sequestered as organic carbon from the soil, during decomposition processes. Many agronomic practices, forestry and conservation, including best management practices, lead to a beneficial net gain in soil carbon fixation [13] [25].

5. The role of mulberry cultivation in the level of CO₂ mitigation.
Mulberry production is the starting point for sericulture. It presents a rapid growth and begins to produce substantial amounts of leaves for the cultivation of silkworm after one year of planting [17]. Srikantaswamy and Bindroo [13] argue that the production of mulberry biomass has attractive qualities to sequester carbon because of its rapid growth and wide adaptability.

Studies were conducted at the Central Sericulture Research and Training Institute in Mysore, Karnataka, India, for five years, with five varieties of mulberry test, identified as (G-4, S- 36, RC-1, V-1 and S-13). The aim was to identify the carbon sequestration rate for the sustainable production of these crops [13].

The tests were carried out under different cultivation practices, with combined application of organic and inorganic fertilizers recommended with soil preparation (T0), totally organic inputs followed by
management of the crop residues and no-tillage without inorganic fertilizer (T1) and totally chemical fertilizers without application of organic inputs with no-tillage (T2) [13].

The variety G-4 (in T0 treatment) mitigates about total of 76 tonnes of CO$_2$ per hectare per year (Table 2) and it is more like Brazilian varieties. For the calculation, according to the authors, the carbon stock is calculated from the biomass produced. In order to calculate the above-ground carbon stock, multiply the biomass above ground level by 0.45. According to the authors, biomass produced below ground level is determined by multiplying the biomass value above ground level by factor 0.26 and CO$_2$e was calculated by multiplying the carbon stock by 3.6 [13] [26].

Table 2. Biomass production and CO$_2$ mitigation level in mulberry cultivars in different practices

<table>
<thead>
<tr>
<th>Varieties/Treatment</th>
<th>AGL biomass production tonne/ha/yr</th>
<th>Carbon stock tonne/ha/yr</th>
<th>CO$_2$ mitigation level tonne/ha/yr</th>
<th>BGL biomass production tonne/ha/yr</th>
<th>Carbon stock tonne/ha/yr</th>
<th>CO$_2$ mitigation level tonne/ha/yr</th>
<th>Total carbon stock tonne/ha/yr</th>
<th>Total mitigation tonne/ha/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>G-4 T0</td>
<td>37.5</td>
<td>16.7</td>
<td>60.3</td>
<td>9.6</td>
<td>4.3</td>
<td>15.6</td>
<td>21.0</td>
<td>75.9</td>
</tr>
<tr>
<td></td>
<td>T1</td>
<td>30.6</td>
<td>13.7</td>
<td>49.5</td>
<td>7.9</td>
<td>3.2</td>
<td>11.8</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>24.41</td>
<td>11.3</td>
<td>46.8</td>
<td>6.3</td>
<td>2.8</td>
<td>10.2</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>T0</td>
<td>47.7</td>
<td>21.5</td>
<td>77.40</td>
<td>12.4</td>
<td>5.5</td>
<td>20.0</td>
<td>79.5</td>
</tr>
<tr>
<td>S-36 T1</td>
<td>39.81</td>
<td>17.9</td>
<td>64.5</td>
<td>10.3</td>
<td>4.6</td>
<td>16.7</td>
<td>22.5</td>
<td>81.1</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>34.05</td>
<td>15.3</td>
<td>55.1</td>
<td>8.8</td>
<td>3.9</td>
<td>14.0</td>
<td>69.2</td>
</tr>
<tr>
<td></td>
<td>T0</td>
<td>35.05</td>
<td>16.5</td>
<td>59.4</td>
<td>9.1</td>
<td>3.9</td>
<td>14.0</td>
<td>73.4</td>
</tr>
<tr>
<td>RC-1 T1</td>
<td>41.05</td>
<td>18.4</td>
<td>66.4</td>
<td>10.6</td>
<td>4.7</td>
<td>17.2</td>
<td>23.2</td>
<td>83.6</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>32.6</td>
<td>14.6</td>
<td>52.8</td>
<td>8.4</td>
<td>3.8</td>
<td>13.6</td>
<td>66.6</td>
</tr>
<tr>
<td>V-1 T0</td>
<td>42.56</td>
<td>19.1</td>
<td>68.9</td>
<td>11.0</td>
<td>4.9</td>
<td>17.8</td>
<td>24.1</td>
<td>86.6</td>
</tr>
<tr>
<td></td>
<td>T1</td>
<td>53.2</td>
<td>23.9</td>
<td>86.2</td>
<td>13.8</td>
<td>6.2</td>
<td>22.3</td>
<td>108.6</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>39.7</td>
<td>17.4</td>
<td>62.6</td>
<td>10.0</td>
<td>4.5</td>
<td>16.2</td>
<td>78.92</td>
</tr>
<tr>
<td>S-13 T0</td>
<td>39.06</td>
<td>18.0</td>
<td>64.8</td>
<td>10.3</td>
<td>4.6</td>
<td>16.8</td>
<td>22.6</td>
<td>79.4</td>
</tr>
<tr>
<td></td>
<td>T1</td>
<td>46.02</td>
<td>20.7</td>
<td>74.4</td>
<td>11.9</td>
<td>5.3</td>
<td>19.3</td>
<td>93.82</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>37.42</td>
<td>16.8</td>
<td>61.3</td>
<td>9.7</td>
<td>4.4</td>
<td>15.9</td>
<td>76.3</td>
</tr>
</tbody>
</table>

Source: Adapted from Srikantaswamy and Bindroo [13].

6. Positive correlations between silk garments and carbon footprint mitigation

Applying the calculations of the study performed by Srikantaswamy and Bindroo [13], Garcia Jr [27] demonstrated the carbon mitigation rate of mulberry trees in Brazil.

The average production of above-ground biomass in 4,338 ha of mulberry fields in Brazil in the year 2015 was 50.40 tonne/ha/year [11]. The biomass value above ground level was 40 tonne/ha/year [12], thus, according to the calculation, the above ground level carbon stock is estimated at 18.0 tonne/ha/year in the Brazilian mulberry fields. The biomass value below ground of carbon stock in these mulberry fields is 4.68 tonne/ha/year. The total carbon stock is 22.68 tonne/ha/year, resulting in a CO$_2$e equivalent of 81.65 tonne/ha/year, as shown in Table 3.

The averages production of Brazilian cocoons is 654 kg/ha/year [11]. The averages content of Brazilian silk in cocoons is 17 %, which multiplied by 654 kg/ha/year, results in a production of 111 kg of silk fiber/ha/year [27] [28].

In this way, considering that the Brazilian sericulture production is of 111 kg of silk fiber/ha/year and using the same bases of analysis from the studies of Srikantaswamy and Bindroo [13], it is possible to estimate that the Brazilian mulberry trees attenuate 81.650 tonne CO$_2$e/ha/year. Furthermore, dividing 81.650 CO$_2$e/ha/year by the 111 kg of silk fiber/ha/year, it is obtained a CO$_2$e mitigation of 735 times the weight of the silk fiber produced by the mulberry area [27].
Another correlation that points to the positive and sustainable behavior of sericulture can be observed in the fact that the production of 111 kg of silk fiber/ha/year is based on the existence of 13,200 mulberry trees per hectare [28]. Therefore, the contribution of each mulberry tree is equal to 111 kg divided by 13,200 mulberry trees resulting in 0.0084 kg/mulberry tree or 8.4 grams/mulberry tree. If considered that a silk blouse weight is near 90 grams, each of them is related to the existence of 10 mulberry trees [27].

7. Conclusion
Reducing the carbon footprint is an important issue for humankind in order to protect the planet for present and future generations. In this context, textiles are much more than a primary need for individuals. Carbon footprint analysis of textiles indicates that many improvements are still needed in the product life cycle and selecting low-emission fibers is a necessary intervention.

The present study focused on the positive aspects of sericulture for the mitigation of the carbon footprint taking in account in calculations the effects of plantation of mulberry trees. The mulberry fields attenuate CO₂ equivalent at a ratio of near 735 times the weight of produced silk fiber per cultivated area. Thus, there is an indication of a positive correlation between silk garments and carbon footprint mitigation. At the same time, additional researches are needed in order to identify and evaluate methods to advertise this positive correlation in order to contribute to a more sustainable fashion industry.

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Hemp Fiber for Furnishing Applications

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Abstract. The primary objective of the study was to compare and contrast the performance characteristics of 100% woven cotton and 100% woven hemp fabrics for furnishing applications. Results obtained showed no difference between cotton and hemp fabrics in terms of colorfastness to crocking; oily stain release; flammability; tearing strength; breaking strength and elongation. For colorfastness to light, the hemp fabrics in this study exhibited noticeable color change. With regard to colorfastness to water, hemp fabrics performed satisfactorily indicating that steam cleaning of hemp furnishing fabrics in this study is not a concern. For abrasion resistance, the performance of hemp fabrics was slightly less than the cotton fabrics in the study. In conclusion, based on test results and benchmark comparisons, this study indicates that hemp is a viable fiber for use in furnishing applications.

1. Introduction
Refined resources such as petroleum, which are currently used for manufacturing synthetic fibers are rapidly depleting. It is estimated that the supply of fossil fuels such as crude oil are only expected to last for another 50-60 years, with world conventional oil production peaking between 2021 and 2112 [1]. Moreover, manufacture of synthetic fibers is not a closed loop process meaning that by-products cannot be processed back into the production cycle. During production of synthetic fibers such as nylon or polyester, volatile monomers and solvents that contribute to water and air pollution are released into the atmosphere [2]. It is imperative, therefore, that professionals in the textile industry begin to consider alternative resources for raw material used for fiber. It is doubly crucial that while considering alternative resources; sustainable, renewable and less polluting natural fibers be considered for uses hitherto dominated by synthetic fibers.
A possible solution to the current dilemma is the bast fiber, hemp. Hemp is often praised as being an excellent rotational crop, requiring little use of pesticides, and has the reputation of purifying soil contaminated with heavy metals. The goal of this investigation was to bring awareness to the possibility of using hemp for furnishing applications by benchmarking the results of standardized tests against another natural fiber; cotton. The investigation was guided by ASTM International and AATCC (American Association of Textile Chemists and Colorists) standards [3]. ASTM Performance Specifications Designation D 3597 lists all specifications for woven upholstery fabric, which were the guidelines to test the performance characteristics of 100% woven hemp fabrics [4]. Specific objectives were to compare and contrast the performance characteristics of 100% woven cotton and 100% woven hemp fabrics of different weave structures with regard to colorfastness to crocking, colorfastness to light, soil release, colorfastness to water, flammability, abrasion resistance, tearing strength, breaking strength and elongation.

2. Materials and Methods
The hemp and cotton fabrics consisted of three different weave structures: plain, twill, and modified twills. The color of the plain weave cotton and hemp fabrics were black. The color of the cotton twill fabric was red and the color of the hemp twill fabric was brown. The modified twill cotton fabric was navy blue and the modified twill hemp fabric was undyed. The colorfastness to crocking of wet and dry samples were tested using AATCC Test Method 8. For testing colorfastness to light, fabric samples were exposed in an Atlas Suntest XLS+ Weatherometer chamber with the following parameters: Black Standard Temperature (BST): 63°C; Phase time: 300 minutes; Irradiance: 500 W/m²; final dosage of 9,000 KJ/m². Each specimen was laid flat, side by side, parallel to the machine (warp direction), and mounted to a white cardstock backing. Samples were compared and evaluated under fluorescent light using the AATCC Gray Scale for Color Change. A grade of 5 represents negligible color change and Grade 1 represents the most drastic color change. AATCC Test Method 130 was used to measure the ability of a fabric to release oily stains during cleaning (laundering) and AATCC Test Method 107 was used to test colorfastness to water. ASTM Test Method D 6413 was used to guide the flammability test for the woven upholstery fabrics. For testing abrasion resistance, ASTM Test Method D 3884 was followed. ASTM Test Method D 2261 (single rip procedure) guided tearing strength tests of hemp and cotton fabrics. To test breaking strength and elongation of hemp and cotton fabrics, ASTM Test Method D 5034 was used. Both wet and dry tests were conducted. For wet testing, test specimens were immersed in distilled water for approximately 15 minutes and were tested immediately afterward.

3. Results and Discussion
3.1. Colorfastness to crocking
The ratings for dry and wet crocking tests are listed in Table 1. A grade of 5 indicates negligible or no color transfer and a grade of 1 is the lowest rating on the AATCC Chromatic Transference Scale. Each grade represents an average of 5 samples. According to ASTM specification requirements D 3597, fabrics must attain a minimum acceptable grade of 4 for the dry crocking test and a minimum grade of 3 for wet crocking in order to be deemed suitable for upholstery fabric. The black hemp plain weave fabric did not pass the minimum requirement with a rating of 2.3 for dry and wet tests. Similarly, the cotton plain weave (black) fabric did not meet the minimum requirements with a grade of 3.0 for the dry test and 1.5 for the wet test. The brown hemp twill fabric met the minimum requirement with a grade of 4 for both dry and wet tests. In contrast, the red cotton twill fabric passed the dry crocking test but failed the wet crocking
test with grades of 4 and 2.5, respectively. The modified twill hemp fabric was undyed; a grade for color evaluation is not available.

### Table 1. Colorfastness to Crocking

<table>
<thead>
<tr>
<th></th>
<th>Hemp</th>
<th>Cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Wet</td>
</tr>
<tr>
<td>Plain</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Twill</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Modified twill</td>
<td>n/a*</td>
<td>n/a*</td>
</tr>
</tbody>
</table>

*The modified twill hemp fabric was undyed; color evaluation is not available.

3.2. Colorfastness to light

Fabric specimens were exposed for five hours under an artificial light source simulated by the Xenon-Arc Lamp. Color change was evaluated under fluorescent light in a color assessment cabinet. Colorfastness to light ratings for hemp and cotton fabrics are given in Table 2. A grade of 5 indicates negligible or no color change and a grade of 1 is the lowest rating on the AATCC Gray Scale for Color Change. Each grade represents an average of 5 samples.

### Table 2. Colorfastness to Light

<table>
<thead>
<tr>
<th></th>
<th>Hemp</th>
<th>Cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>4</td>
</tr>
<tr>
<td>Plain</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Twill</td>
<td>1-2</td>
<td>4-5</td>
</tr>
<tr>
<td>Modified twill</td>
<td>n/a*</td>
<td>4-5</td>
</tr>
</tbody>
</table>

*The modified twill hemp fabric was undyed; color evaluation is not available.

According to ASTM specification requirements D 3597, upholstery fabrics must attain a minimum grade of 4 for colorfastness to light in order to pass. The results of the colorfastness to light tests indicate that hemp performed poorly, with a grade of 2 or lower, suggesting that the dyes used on hemp are more prone to color change than cotton. In contrast, the cotton fabrics had grades of 4-5 or higher, suggesting that the dyes used for cotton were more resistant to light than hemp. The AATCC test method for Colorfastness to Light states that the total color difference can be assessed by measuring samples on a spectrophotometer and comparing the results to a reference (control) sample. To confirm the visual assessment of color change for hemp and cotton fabrics, the total color difference was calculated using CIELAB L*a*b* values. For the black cotton plain weave fabric, the average value of ΔE was 1.16 whereas for the black plain weave hemp fabric had a total color change (ΔE) of 2.87. The brown twill hemp fabric had ΔE of 3.90, which indicates that it had the greatest amount of color change among all the tested fabrics. Total color change (ΔE) for the red cotton twill fabric was 0.93. The navy blue cotton (modified twill) fabric had a total color change of 0.66, which indicates that this fabric performed the best of the three cotton fabrics. Spectrophotometric data confirmed the results of visual assessment.

3.3. Soil Release

The grades for soil release of hemp and cotton fabrics obtained by using the AATCC Stain Release Replica are listed in Table 3. Each grade represents an average of 5 samples. Each of the cotton plain weave, twill, and modified twill fabrics and the plain, and twill hemp fabrics had a grade of less than 3. This indicates that all of these fabrics have poor resistance to oil stains and stain spots would be visible on the upholstery
even after laundering. Only the modified twill hemp fabric had a rating higher than 3 and displayed good stain resistance.

### Table 3. Soil Release: Oily Stain Release

<table>
<thead>
<tr>
<th></th>
<th>Hemp</th>
<th>Cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain</td>
<td>2.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Twill</td>
<td>1.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Modified twill</td>
<td>4.4</td>
<td>1.3</td>
</tr>
</tbody>
</table>

3.4. **Colorfastness to water**

For colorfastness to water evaluation, hemp and cotton fabrics were immersed in water for 15 minutes, passed once through a laboratory wringer, and stacked between plastic plates onto the perspiration tester. They were placed into a drying oven for 14 hours. Multi-fiber samples containing wool, rayon, silk, nylon, cotton, acetate, and polyester yarns were attached to each sample during wetting and drying. Color transfer was evaluated using the Gray Scale for Staining. A grade of 5 represents negligible or no color transfer and a grade of 1 is the most drastic color transfer. The grades reported in **Table 4** are the average of 5 samples. As shown in Table 4, the black hemp plain weave and brown hemp twill fabric had grades of 4 and higher on the Gray Scale for Staining. In contrast, the cotton fabrics had lower grades, particularly the red cotton twill fabric. The greatest amount of staining for the red cotton twill fabric occurred on rayon, cotton, and silk. Similarly, the navy blue cotton (modified twill) fabric had grades of 3 for staining on rayon and a grade of 3-4 and 3 for staining on cotton. The black cotton plain weave fabric had grades of 4 or higher for staining on all fiber types with the exception of rayon, which received a grade of 3. Wool, acetate, and polyester were relatively unaffected by staining, with grades of 3-4 or higher for all hemp and cotton fabrics. It was duly noted that staining on all cotton fabrics, except for the red cotton twill, occurred in a spotted pattern as opposed to an even spread of color transfer.

### Table 4. Colorfastness to Water

<table>
<thead>
<tr>
<th></th>
<th>Hemp</th>
<th>Rayon</th>
<th>Silk</th>
<th>Nylon</th>
<th>Cotton</th>
<th>Acetate</th>
<th>Polyester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemp</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plain</td>
<td>4</td>
<td>4-5</td>
<td>4-5</td>
<td>4</td>
<td>4</td>
<td>4-5</td>
<td>4</td>
</tr>
<tr>
<td>Twill</td>
<td>4-5</td>
<td>4-5</td>
<td>4</td>
<td>4-5</td>
<td>4-5</td>
<td>4-5</td>
<td>4</td>
</tr>
<tr>
<td>Modified twill</td>
<td>n/a*</td>
<td>n/a*</td>
<td>n/a*</td>
<td>n/a*</td>
<td>n/a*</td>
<td>n/a*</td>
<td>n/a*</td>
</tr>
<tr>
<td>Cotton</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plain</td>
<td>4-5</td>
<td>3</td>
<td>4</td>
<td>4-5</td>
<td>4</td>
<td>4-5</td>
<td>5</td>
</tr>
<tr>
<td>Twill</td>
<td>3-4</td>
<td>1-2</td>
<td>2-3</td>
<td>3-4</td>
<td>1-2</td>
<td>4</td>
<td>3-4</td>
</tr>
<tr>
<td>Modified twill</td>
<td>4-5</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4-5</td>
<td>4</td>
</tr>
</tbody>
</table>

*The modified twill hemp fabric was undyed; color evaluation is not available.*

3.5. **Flammability**

Flammability of textiles refers to their burning behavior and particularly to the ease of ignition and continued burning after ignition. To compare the flame resistance of the hemp and cotton fabrics; the burn time, afterglow time and char length were determined by the vertical flame test method. The average burn times of the hemp and cotton fabrics in the warp and filling directions are listed in Table
5. Each value represents the average of 5 samples. Afterglow times are reported in Table 6. Afterglow times represent the amount of time that the fabric continued to glow after flame was removed.

<table>
<thead>
<tr>
<th>Table 5. Burn time (in seconds) of cotton and hemp fabrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warp</td>
</tr>
<tr>
<td>Plain</td>
</tr>
<tr>
<td>Twill</td>
</tr>
<tr>
<td>Modified twill</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 6. Afterglow time (in seconds) of cotton and hemp fabrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warp</td>
</tr>
<tr>
<td>Plain</td>
</tr>
<tr>
<td>Twill</td>
</tr>
<tr>
<td>Modified twill</td>
</tr>
</tbody>
</table>

According to the test standard, for a fabric to pass, the mean char length must not exceed seven inches. In addition, no single sample should have a char length of ten inches. The char length for all fabrics (cotton and hemp) was more than ten inches. Accordingly, none of the fabrics in this study passed the vertical flame test.

3.6. Abrasion resistance
Abrasion testing serves best to make comparisons between or among different fabrics for the same end use. For this study, the number of cycles until yarn rupture or an end-point of 500 cycles was recorded. Table 7 lists the average number of cycles for each fabric. Of the three different weave structures, the plain weave fabrics had the best abrasion resistance, suggesting that the higher number of interlacings and absence of floating yarns result in better abrasion resistance. The twill and modified twill fabrics have floating yarns that are more exposed and susceptible to abrasion.

<table>
<thead>
<tr>
<th>Table 7. Average number of cycles until yarn rupture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemp</td>
</tr>
<tr>
<td>Avg. number of cycles</td>
</tr>
<tr>
<td>Plain</td>
</tr>
<tr>
<td>Twill</td>
</tr>
<tr>
<td>Modified twill</td>
</tr>
</tbody>
</table>

The aesthetic appearance of fabrics before and after abrasion was also observed. Hemp fabrics
exhibited highly noticeable frosting (color change due to flat localized abrasion) across all weave structures. For cotton fabrics, the plain weave and modified twill fabrics exhibited frosting the most whereas the twill fabric had the least amount of frosting. In addition to frosting, pilling was observed on several fabrics. Pilling occurred on both the cotton and hemp plain weave fabrics and to a lesser extent on the twill and modified twill fabrics.

3.7. Tearing strength
To measure the tearing strength of hemp and cotton fabrics, the single rip procedure at a constant rate of extension was used (ASTM D 2261). The results in Tables 8 and 9 represent the average of five samples in the warp and filling direction in dry and wet conditions respectively.

| Table 8. Dry tearing strength (lbf) of hemp and cotton fabrics |
|------------------|------------------|------------------|------------------|------------------|
|                  | Hemp             | Cotton           |
|                  | Warp     | Filling | Warp     | Filling |
| Plain            | 9.9       | 9       | 11.4     | 8.4     |
| Twill            | 36.8      | 33.2    | 10.4     | 8.2     |
| Modified twill   | 40.1      | 40.5    | 8.2      | 6.4     |

| Table 9. Wet tearing strength (lbf) of hemp and cotton fabrics |
|------------------|------------------|------------------|------------------|------------------|
|                  | Hemp             | Cotton           |
|                  | Warp     | Filling | Warp     | Filling |
| Plain            | 16.1     | 14      | 16.6     | 13      |
| Twill            | 50.6     | 29.4    | 11.6     | 7.4     |
| Modified twill   | 42.4     | 31.4    | 12.9     | 8.2     |

As the data in the tables show, the hemp plain weave fabric had lower tearing strength in the dry test compared to the cotton plain weave fabric. The hemp twill and hemp modified twill fabric had higher tearing strength than the cotton twill and modified twill fabric in both directions for both dry and wet tests. To illuminate the results more, the GLM procedure for the least square means was done at a significance level of 0.05. The two-way interaction between fiber and structure did not show a significant difference between hemp and cotton plain weave fabrics with a p-value of 0.97. However, there was a significant statistical difference between the hemp and cotton twill fabrics and hemp and cotton modified twill fabrics with p-values < 0.0001. However, since the minimum requirement for tearing strength of upholstery fabric is 6 lbf, all fabrics in this study met the specification requirement and are acceptable for use in upholstery.

3.8. Breaking strength and elongation
For breaking strength tests, the average breaking force of five specimens for each weave structure of hemp and cotton was calculated. Results are reported in Tables 10 and 11. These values indicate the maximum breaking force exerted on the specimen. Results from breaking tests show that warp yarns had a higher breaking strength than filling yarns. In addition, it was also confirmed that for cellulosic fabrics the breaking strength of wet fabrics were greater than dry fabrics.
Table 10. Dry breaking strength (lbf) of hemp and cotton fabrics

<table>
<thead>
<tr>
<th></th>
<th>Hemp</th>
<th></th>
<th>Cotton</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Warp</td>
<td>Filling</td>
<td>Warp</td>
<td>Filling</td>
</tr>
<tr>
<td>Plain</td>
<td>260.9</td>
<td>172.0</td>
<td>371.6</td>
<td>310.6</td>
</tr>
<tr>
<td>Twill</td>
<td>364.6</td>
<td>182.6</td>
<td>385.2</td>
<td>165.1</td>
</tr>
<tr>
<td>Modified twill</td>
<td>281.3</td>
<td>210.8</td>
<td>223.6</td>
<td>142.2</td>
</tr>
</tbody>
</table>

Table 11. Wet breaking strength (lbf) of hemp and cotton fabrics

<table>
<thead>
<tr>
<th></th>
<th>Hemp</th>
<th></th>
<th>Cotton</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Warp</td>
<td>Filling</td>
<td>Warp</td>
<td>Filling</td>
</tr>
<tr>
<td>Plain</td>
<td>342.1</td>
<td>226.2</td>
<td>533.6</td>
<td>438.5</td>
</tr>
<tr>
<td>Twill</td>
<td>694.0</td>
<td>365.5</td>
<td>277.4</td>
<td>219.7</td>
</tr>
<tr>
<td>Modified twill</td>
<td>499.7</td>
<td>386.8</td>
<td>304.1</td>
<td>205.7</td>
</tr>
</tbody>
</table>

Statistical analysis at a significance level of 0.05 showed that the breaking strength of hemp and cotton fabrics were significantly different. The cotton plain weave fabric had higher breaking strength than the hemp plain weave fabric. Conversely, the hemp twill and modified twill fabrics displayed higher breaking strength than the comparable cotton fabrics. Since the minimum requirement for breaking strength of upholstery fabric is 50 lbf, all fabrics in this study met the specification requirement and are acceptable for use in upholstery.

Elongation of the hemp and cotton fabrics can be defined as the change in length due to stretching of the fabric. Hemp and cotton fabrics, unless blended with elastane or other elastic fiber, have no elastic recovery. Once elongated, the fabric does not return to its original length. Tables 12 and 13 list the elongation results of hemp and cotton fabrics.

Table 12. Dry elongation (inches) at the breaking point of hemp and cotton fabrics

<table>
<thead>
<tr>
<th></th>
<th>Hemp</th>
<th></th>
<th>Cotton</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Warp</td>
<td>Filling</td>
<td>Warp</td>
<td>Filling</td>
</tr>
<tr>
<td>Plain</td>
<td>0.9</td>
<td>0.3</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Twill</td>
<td>0.6</td>
<td>0.2</td>
<td>1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Modified twill</td>
<td>0.6</td>
<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 13. Wet elongation (inches) at the breaking point of hemp and cotton fabrics

<table>
<thead>
<tr>
<th></th>
<th>Hemp</th>
<th></th>
<th>Cotton</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Warp</td>
<td>Filling</td>
<td>Warp</td>
<td>Filling</td>
</tr>
<tr>
<td>Plain</td>
<td>0.9</td>
<td>0.4</td>
<td>1.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Twill</td>
<td>0.9</td>
<td>0.3</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Modified twill</td>
<td>0.7</td>
<td>0.5</td>
<td>0.9</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Statistical analysis at a significance level of 0.05 indicated that the amount of elongation between hemp plain weave and cotton plain weave fabrics was not significantly different (p-value = 0.11). There was a significant difference (p-value = 0.003) in elongation between the hemp twill and cotton twill fabrics. Elongation of the hemp modified twill and cotton modified twill fabrics were not significantly different with a p-value of 0.10. There is no minimum or maximum elongation requirement for upholstery fabric according to ASTM performance specifications.

4. Results and Discussion

Based on the data obtained, it is concluded that the colorfastness to crocking was satisfactory in the case of both the hemp and cotton twill fabrics but unsatisfactory for the plain weave fabrics. The results from dry and wet crocking tests are influenced by the amount of dye penetration, proper selection of dyestuffs, and finishes present on the fabric.

Based on the total color difference (ΔE) values, the hemp fabrics had the greatest amount of color change on exposure to light. The results suggest that the use of hemp in home furnishings may be limited to indoor upholstery applications. Typically, indoor home furnishings are not exposed to a great amount of sunlight. However, in cases where hemp-upholstered furniture sits near an uncovered window, findings suggest that noticeable color change may occur within a short period of time. For indoor hemp-upholstered furniture that will be exposed to sunlight for prolonged periods, it is suggested that a treatment be applied that will provide resistance to color change caused by light.

Visual comparisons between specimens for oily stain release are subjective in nature. It was found that hemp fabrics had slightly higher grades than the cotton fabrics, particularly the modified twill and the plain weave fabrics. Cotton fabrics had grades of less than 2, which indicate poor stain removal compared to the hemp fabrics. The results from the oily stain release test suggest that none of the hemp and cotton fabrics had a soil or a stain release finish applied to them. Although the soil release test is not required for determining suitability for upholstery fabric, it demonstrates a fabric’s propensity for staining due to oily substances. It is possible that the depth of color or lightness of the sample influenced higher grades for the hemp plain weave and hemp modified twill fabrics. Upholstered furniture serves as seating for everyday use or social gatherings, which can lead to incidence of spilled food or beverage containing oil or fatty substances. In this case, to prevent oil staining, a soil release finish should be applied to hemp-upholstered furniture in high-traffic areas.

According to AATCC Test Method 107, the colorfastness to water test measures the resistance to water of dyed, printed, or other colored textile yarns and fabrics. As a whole, the hemp fabrics that were tested performed well, while the cotton fabrics were graded lower and failed to pass the ASTM specification requirements for upholstery fabric. The multi-fiber sample exhibited the greatest amount of staining against the cotton fabrics. The hemp fabrics had negligible staining on the multi-fiber sample when exposed to water at 100°F, which indicates good colorfastness to water. The colorfastness to water test indicates how resistant a fabric is to cleaning. Dye loss and color transfer may be an issue when upholstery steam cleaners are used.

All hemp and cotton fabrics tested failed the flame resistance test by exceeding a maximum char length of 10 inches. The ease of ignition for hemp and cotton fabrics suggests that flame spread can be severe. This poses a serious threat of injury incurred by victims of an upholstery-related fire. Generally, fire is unpredictable and the flammability of upholstery fabric can be affected by other factors such as textile items in the immediate surrounding area. The test results indicate that both cotton and hemp fabrics have poor flame resistance without a proper flame resistant or flame retardant finish. The high amount of smoke and afterglow time indicates the hazard that untreated hemp and cotton fabrics pose when used for upholstery fabric.

The abrasion resistance of a fabric is subject to various factors, such as fiber content, yarn size, yarn twist, fabric construction, fabric count, fabric thickness, and weight. Abrasion is a crucial measure of durability of upholstery fabric as well as a factor in consumer satisfaction. If the development of holes, pilling, or frosting occurs as a result of abrasion in actual wear, the consumer is likely to be dissatisfied with a furniture item upholstered in that particular fabric. The number of cycles until yarn rupture is a
subjective evaluation. However, since cotton lasted through a much higher number of cycles in all three different weave structures, it can be suggested that cotton has better abrasion resistance than hemp among the fabrics investigated in this study.

The tearing strength of upholstery fabric gauges how well the upholstery fabric behaves under stress, for example when seated on or when pulled at the seam. There was not a significant difference in tearing strength between wet and dry tests. Additionally, all fabrics were acceptable according to ASTM specifications. It is also concluded that a hemp fabric with a twill or modified twill weave structure would be more ideal for upholstery use since their tearing strength values were significantly higher than plain weave fabrics.

There was no significant difference between hemp and cotton in terms of breaking strength. All the fabrics met the minimum ASTM specification requirement for breaking strength of upholstery fabric. It is further noted that twill or modified twill fabrics are more suitable for furniture applications. Also, both hemp and cotton fabrics have poor elastic recovery, meaning when they are stretched, they do not return to their original length or shape. Aesthetically, this can be problematic if upholstery on furniture becomes loose and stretched out due to stress on the fabric over time.

References
Fashion garment manufacturing – FGM and cyclability theory

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²Universidade de São Paulo, FAU, Departamento de Projeto, R. do Lago, 876 - Butantã, São Paulo - SP, 03178-200, Brasil

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Abstract. This article, derived from an ongoing research, presents the possibilities of reducing the inappropriate disposal of textile residues generated by the fabric cutting sector of the Fashion Garment Manufacturing (FGM). The raw material used is very varied, resulting in a large number of productive processes. FGM produces clothing that has as its main features a short life cycle, a high rate of diversification and differentiation, and small production batches, resulting in few similar parts. The production process is differentiated according to the characteristics of the fabric and the look of the garment. During the production process, at least 10% of textile waste is generated during the cutting process, which is constantly discarded in an inadequate way. The Cyclability theory is researched aiming at the possibility of reduction in the generation of waste and elimination of inappropriate disposal. The case study presents the action research carried out in three small Brazilian companies to study the applicability of the Cyclability theory.

1. Introduction
The Fashion Garment Manufacturing – FGM is the most sensitive link of the Textile Chain to planned obsolescence, resulting in an acceleration of the process of development and production of short life cycle items. The main raw materials of this product are fabrics composed of yarns with pure composition or mixtures of natural, synthetic and artificial fibers. The main end product of the chain is in the fashion industry, clothing [1]. There are numerous types of waste generated in the textile chain being discarded, mainly without major concern with the impacts to the environment.

In this research there are theoretical methodological sources of different authors, among them [2] Yin and [3] Lakatos, who did not present actions in order to enable the execution of scientific research, data collection and information of a subject inserted in a little empirical environment studied and documented. Case study and action research start from a qualitative research in which the "what", "why" and "how" questions form the basis of research and study.

The article presents an action research carried out in three complementary companies as a solution for a solid textile waste management. A company that manufactures uniforms, a textile defibration company and a non-governmental organization (NGO) that uses textile waste as raw material. During the action research there was a significant reduction in the generation of waste from the cutting
The remainder of the unused waste was defibrated. The material was absorbed by the automobile industry in the production of acoustic lining.

2. Theoretical basis - Textile Chain
The Fashion Garment Manufacturing – FGM is part of the Textile Chain, and each link comprises a set of industries forming a network of inputs that have been transformed into final products in order to meet the demand of final consumers. The sequence of production processes suffers more or less influence of the fashion cycle at each stage of the Textile Chain [1]. The image in Figure 1 shows all the links in the chain and the interrelationship between the participating industries. The main axis shows the production sequence that begins in the fibers ending in the retail, going through the production of fashionable clothing. In its surroundings are observed the adjacent industries that give support for the fashion clothing to materialize, such as those of beneficiation and producers of supplies and distribution equipment. This entire network is served by the machinery industry that has evolved over the past 60 years to precede this chain. It is noticed that fashion, through the Fashion Bureaux and Textile Design, influences the chain, more subtly in the fibers, and more aggressively in the retail.

![Figure 1. Textile Chain](image)

2.1. Fashion Clothing
In each new season, the fashion clothing industry, influenced by information from the Fashion Bureaux, provides retailers with a wide variety of new products with novelties in their shapes, colors, materials and textures, making it possible to meet fashion clothing brands that meet the needs of Different consumer markets. The goal is to satisfy the desires of a conservative public, consuming a basic and classic fashion or bold and innovative or the vanguard of fashion and unusual products.
Figure 2 presents a collection of fashion apparel, a set of garment parts developed and produced for distribution in the retail market. It is noticed that the pieces between them are quite differentiated in their forms and volumes of fabrics. In this collection are used several types of fabric, each one with specific characteristics.

3. Fashion Garment Manufacturing - FGM
The FGM production process consumes a large quantity of different types of fabric, such as flat woven, knitted fabric and others, produced with different types of yarn, twist, pure yarn, fiber blend and others, composed of various natural fibers, Artificial or synthetic, causing a great possibility of development of new clothes of fashion. As a result, there is the generation of a wide variety of solid textile waste with high harmful impact on the environment. For each ton of product, approximately 10% of textile waste is generated. The Brazilian textile industry produces, on average, 1.878 million tons of final products. [4]. Thus, 190,000 tons of unused textile waste per year are disposed of incorrectly. According to the Brazilian law PLN No. 12,305/10, which establishes the National Solid Waste Policy (PNRS), entrepreneurs should be responsible for the proper management of waste generated.

There are bibliography citing studies that have succeeded in solutions related to the management of textile waste. Many theories are in their stages of implementation of the processes of reduction, reuse and recycling of textile materials.

4. Cyclability
The theory of Design for Cyclability described by Dr. Kate Goldsworthy [5] describes three items intended for Zero Waste Future and Creating Closed Loop Systems: Now upcycling by design, Near Design for Cradle-2-Cradle, Future Design for Material Ecologies, as shown in Figure 3.

Figure 3. Creating Closed Loop Systems by Dr. Goldsworthy. Source: (Earley, 2012)

- Now Upcycling by Design: limited materials with limited life cycles. Although return journeys can be designed at the end-of-life, this approach only postpones the end of the discarded material at landfill, where it may never biodegrade, it may degrade very slowly or may add harmful materials to the environment as it degrades.

- Near Design for Cradle-2-Cradle: limited materials with unlimited life cycles. By considering the barriers to recycling as part of the design brief, connected loops can be built into the material's future
life from the outset. In a closed-loop, materials would not lose their value and would be designed to be recycled indefinitely.

- Future Design for Material Ecologies: unlimited materials with unlimited cycles. A genuinely sustainable future depends on creating interconnected loops, or cycles, for all industrial commodities. These cycles would be part of a scaled up system of material exchange which is open and dynamic, including all material resources in an infinite industrial ecology.

Other complementary tools seek solutions to these issues and can be included in the new challenges.

5. Ecodesign
Ecodesign is an international concept developed by the World Business Council for Sustainable Development (WBCSD) with a holistic, conscious and proactive approach. It consists of the design of a product or service that aims to minimize the impacts caused to the environment and reduce the debt that society has established with the environment to meet the needs and desires of consumers. Ecodesign discloses respect for the environment and optimization of interactions that occur at all stages of the product life cycle, from raw material extraction, product development, production, packaging, distribution, use, recycling, incineration, etc., considering also the energy consumed in the production and conservation of the product [6].

The know-how of science and engineering is necessary to achieve certain projects and the adaptation between the various operational subsystems in order to produce the appropriate levels of volume and quality, in order to meet the real needs of the consumers. Ecodesign principles and practices have much to contribute to the urgent need for rapid and tangible progress towards a sustainable human economy [7].

6. Ecoproduct
An eco-product must respect the environment and responsibly address all stages of its development from conception to its deterioration [8], as shown in Figure 4a.

![Figure 4a](https://example.com/figure4a.png)

**Figure 4a** Life cycle of ecoproduct. Source: (CARVALHO, 2015)

7. Cradle-to-Cradle – C2C
The Cradle-to-Cradle theory comprises a conception of material use in a circular production system, or circular economy, as opposed to the linear system. This means extracting, manufacturing, using and
again making their waste available as new raw material or a new product, resulting in zero residue [9]. The authors also used concepts to distinguish recycling that results in a material that shows loss of quality, “downcycling”, as opposed to another, more useful and productive, “upcycling”.

The C2C argues that all components and raw materials used or constituents of the production process can be totally reused in the same or a new process after its useful life. This is not recycling. C2C strictly abrogates the elimination of the concept of waste and, as a new paradigm, does not accept the waste of by-products, adopting its complete extinction [10]. C2C determines that materials must necessarily generate new products of equal or greater quality than the first, even if not for the same application or for the same market. The concept advocates that the production process and the raw materials are ecologically efficient and not only efficient. Macdounough & Braungart illustrates the system with a few examples, including biodegradable fibers or intelligent fibers, which enable complete reprocessing in the textile industry, materials designed as biological nutrients such as textiles and packaging made from natural fibers that can biodegrade safely, Restoring nutrients to depleted soil [11].

8. Case Study
The company X produces uniforms for professionals working in the administrative and security area of companies, are social attire, jacket, pants, shirts, skirts. These pieces are produced with flat and composite fabrics of mixed, artificial and natural fibers. Consume in their production approximately 10 thousand kilos of fabrics per week, generating approximately 100 kilos of waste. Two years ago it started a project to reduce its waste disposal during the cutting stage and began to cut parts of the waste in formats that could be used in new products.

These new products are developed and produced by an NGO that welcomes, for the overnight stay, people in situations of extreme vulnerability who live on the streets of the city of São Paulo. These people participated in workshops and learned to produce carpets using the waste as raw material. Figures 4 and 5 show the processes of rugs made of rectangular flaps and of crochet produced with long strips of the sides of the fabrics.

A company defibrillates the waste that does not have dimensions to enable its use. These wastes are processed by machines that, after defibration, form compacted bundles of fibers. These bales are intended for the panel manufacturing and automotive coating industries. Figure 6 shows the volume of debris that is defibrillated and Figure 7 shows the lustrates the bales that are used in the automotive component industry.
9. Analysis and conclusion
The uniforms company began to cooperate with the NGO offering strips and rectangles of fabrics already cut into the necessary dimension for the production of carpets. It is the use of small spaces existing between the parts necessary for the production of uniforms in the company's cutting department.

As a result, time was gained in the production of carpets with increased quality and a 50% reduction of discarded waste was verified and the remainder also being sent to a defibrillator processing company for the production of automotive and acoustic coating panels.

The implementation of the project has shown that it is possible for garment companies to dispose of their waste. It is possible to see the application of the C2C system, also considering that the official responsible for the cutting department, resistant to the new recovery process, did not fully cooperate with the new procedure, from which it can be concluded that much more satisfactory results are possible.

As for the "Future Design for Material Ecologies" phase of "Design for Cyclability", the results depend on a new technological awareness accompanied by the evolution of human consciousness to the values of ethics, transparency, responsibility and desire to correct decades of environmental changes. High values of education, the principles of coexistence and community participation must also be taken into account in order for change to be positive, prosperous and effective.

In addition to legal sanctions, environmental issues have recently begun to show great global importance and brand identity, resulting in a business concern with the proper disposal of solid waste.

References


Abstract. Natural dyes represent an emerging trend in the textile industry and eco-fashion due to the increasing awareness of the sustainability concept, which must be applied to the surrounding environment. In the light of the stated problem, the search for alternative sources of dyes, revealed the new, eco-friendly, biodegradable, non-carcinogenic and sustainable colorant matter, the algal biomass. In the present work, the suitability and viability of printing cotton fabrics with pigments obtained from the red macroalgae *Gracilaria* sp., has been investigated. For this aim, phycoerythrin, the red pigment, was extracted from fresh algal biomass, and used in a laboratory pigment-printing process, employing a natural and synthetic printing paste, for process efficiency comparison. The color values and the rubbing and laundering fastness of the printed substrates were evaluated. Results show that a light pink color can be obtained when applying both tested printing processes, and in terms of color fastness, both printing pastes show good behavior. In conclusion, the algal pigments show a high printing capacity on cotton substrates, either when employing the synthetic conventional paste and; moreover, when applying the more sustainable and eco-friendly natural paste.

1. Introduction

The growing popularity of the sustainability and greening concepts generates an increase in the awareness of the need to protect the environment. When applying these concepts to one of the most demanded industries, the textile industry, research studies exposed the necessity of exploration for more sustainable alternatives to the synthetic products, which are pollution generating. A solution to these needs can be represented by the focus on the reutilization of natural dyes, although they were used for the coloration of goods from ancient times. Nevertheless, dyes originating from vegetable sources are interesting due to the very low dyes’ toxicity[1].

Natural dyes are pigments derived from mineral, animal or plant sources[2], and can be obtained from any part of the plant, such as leaves, fruits, seeds, flowers, bark root, etc[3]. The two biggest disadvantages of plant pigments production are represented by the need of a wide arable land for their cultivation and the CO2 emissions[4].

Regardless of the source, these products, which may be categorized as ‘green’ dyes, are in essence, secondary metabolites produced by the organism[5]. The unique characteristic of secondary metabolites generation presents a scientific and technological challenge.
Taking into consideration the difficulties and inconveniences imposed by the ‘conventional’ natural dyes, this investigation work puts in light another source of natural pigments, namely, the algal biomass, which surpasses the previously mentioned impediments.

In recent years, significant interest has been developed in the commercial utilization of algae, based on their valuable chemical constituents, taking into account the multiple bioactive compounds content with applications in the food, cosmetic, agri- and horticultural sectors and in human health. The main compounds, which present special interest, include pigments, lipids and fatty acids, proteins, polysaccharides and phenolic[6]. Macroalgae contain phycoerythrins and carotenoids, which represent valuable pigments for the textile finishing industry. Phycoerythrin, is a water-soluble, light harvesting protein, which is specialized in the energy transfer chain[7].

There is an increasing interest on the employment of natural dyes in textile processes. Although dyeing with natural dyes is widespread through scientific research, papers on the printing via natural colorants are limited. Pigment printing is considered the easiest printing method[8], and it is defined as the process of fixing insoluble pigments, which have no affinity to the fiber on the textile with binding agents. It is considered the most economical printing process and can be applied to all substrates[9].

This study was focused on the validation of pigment printing of natural dyes, originating from red macro algae, on cotton substrates. To this purpose, phycoerythrin, the red pigment extracted from Gracilaria sp., was used in a laboratory pigment-printing process employing a natural and synthetic printing paste, with the aim of comparing the process efficiency. The color values and the rubbing and laundering fastness of the printed substrates were evaluated and revealed good to excellent color behavior when applied on cotton substrates.

2. Materials and methods

2.1. Pigment cultivation and extraction

Phycoerythrin, red pigment, was extracted from the red macroalgae Gracilaria sp., obtained from Algaplus, Portugal. The fresh algal biomass was collected from large-scale cultivation tanks, in an open-system; and was subjected to one freeze (-20 ºC) - thaw (4 ºC) cycle, in order to obtain the pigment. The extracts were obtained in distilled water at pH=7, after magnetic stirring for 5 hours, under dimmed light. In the extraction process, Ammonium Sulphate (supplied by Sigma-Aldrich, Spain for protein stabilization was added) in a concentration of 20 %, with respect to the biomass weight for protein stabilization. The resulting extract was a solution, which was employed as obtained in the printing process, by adding it to the mother pastes described in table 1.

2.2. Textile finishing process on cotton fabrics

2.2.1. Cotton pretreatment

A mordanting pre-treatment was applied to cotton fabrics in order to increase the affinity dye-cellulosic-fiber, by immersing the fabric substrate in a solution containing 6 % (reported to the dry fabric weight) Cream of Tartar (supplied by Sigma-Aldrich, Spain), for 45 minutes, at 85 ºC.

2.2.2. Printing process

In this study, cotton fabrics (supplied by Intexter UPC, Spain) weighing 200 gr/m², were used for the application of pigment printing process and the natural sources extracts were used directly as dyestuff in the natural and synthetic printing pastes, as shown in table 1.
The fabrics were printed at laboratory scale, using a manual method including a printing screen and scraper; passing the scraper over the cotton fabrics for three times, applying a uniform pressure. The fabrics printed with the synthetic paste were dried in a laboratory type drying oven (supplied by Memmert, Germany) at 80 °C for 10 minutes and cured at 110 °C for 2 minutes. On the other hand, the fabrics printed with the natural paste were dried and cured at room temperature for 24 hours, due to the fact that the binder used in the printing process is self-crosslinking at approximately 20 °C.

2.3. Fabric characterization

2.3.1. Color characterization.

In order to realize the objective color characterization of the printed cotton fabrics, the chromatic coordinates, CIEL*a*b* values, were determined according to the European standard (UNE-EN ISO 105-J01:2000) with the DATACOLOR DC 650 (supplied by DATACOLOR, Spain) apparatus with an illuminant D65 and an observer at an angle of 10º and a diffuse measuring geometry.

2.3.2. Fastness to laundering and rubbing measurements

2.3.2.1. Color fastness to domestic and commercial laundering.

The European standard (UNE-EN ISO 105-C06:2010), was employed for the analysis of the color resistance to laundering, by testing cotton samples of 10×4 cm with the Gyrowash apparatus (supplied by James Heal, United Kingdom). The working conditions were the following: temperature=25 °C, time of work= 45 minutes, 150 ml of water, 0.6 gr of detergent and 10 steel balls. All of the components were added into a canister together with the sample fabrics. At the end of the test, the samples were dried in forced-air circulation dryer.

2.3.2.2. Color fastness to rubbing.

The resistance of the printed fabrics to rubbing was measured and analyzed according to the European standard, UNE-EN ISO 105-X12:2003, which requires the subjection of the cotton samples of about 14×5 cm to the Crockmeter apparatus (supplied by Atlas, Spain) at a temperature of 20 °C with an applied force of 9 N.

Two types of color fastness to rubbing were tested: in dry conditions, where the rubbing was made at 1 cycle per second exercising the rubbing on the fabric and in the same time applying the mentioned force. The wet rubbing was realized in the same manner as the dry method, but with the addition of a previous conditioning phase, in which the fabric was immersed in distilled water until it was reached an impregnation level comprised between 95 % and 100 %.
3. Results and discussions

3.1. Printing process
During the printing process, the algal pigment was used to provide a light red color, as seen in figure 1. The color shades only related with the natural dye extract concentration, binder and fiber type.

Figure 1. Printed cotton fabrics, A. synthetic paste and B. natural paste

3.2. Color characterization and printing efficiency
During the printing process, the phycoerythrin obtained from Gracilaria sp. was used to provide a light red color (pink). As presented in Table 1, the color shades only related with the natural dye extract concentration, binder and fiber type. Table 2 shows that in cotton printing there is a favorable circumstance in the use of natural dyestuff. As known, the L* value represents the lightness of the color (L*= 0 refers to black and L* = 100 refers to white). In the employment of the synthetic paste, it can be observed a slightly lighter color than in the case where the natural paste was employed. In addition, it can be mentioned that the light color obtained was due to the low concentration of colorant employed in the process. Regarding the color area, both types of the printed fabrics are found in the red – yellow area (a*, b*). From the color analysis of the phycoerythrin, it can be stated that a light red color can be obtained with this kind of natural dye and that the intensity of the color depends on the amount of colorant added to the mother paste, in both synthetic and natural printing processes.

Table 2. Color values of the printed cotton

<table>
<thead>
<tr>
<th></th>
<th>PE with synthetic paste</th>
<th>PE with natural paste</th>
</tr>
</thead>
<tbody>
<tr>
<td>L*</td>
<td>92.99</td>
<td>92.5</td>
</tr>
<tr>
<td>a*</td>
<td>2.61</td>
<td>2.73</td>
</tr>
<tr>
<td>b*</td>
<td>3.91</td>
<td>2.71</td>
</tr>
<tr>
<td>Chroma (C*)</td>
<td>4.7</td>
<td>3.85</td>
</tr>
<tr>
<td>Hue angle (h*)</td>
<td>56.31</td>
<td>44.75</td>
</tr>
</tbody>
</table>

Table 3. Color intensity and lightness differences between the synthetic paste printed cotton fabrics and the ones printed with the natural paste

<table>
<thead>
<tr>
<th></th>
<th>Cotton synthetic vs. natural paste</th>
</tr>
</thead>
<tbody>
<tr>
<td>∆L*</td>
<td>0.49</td>
</tr>
<tr>
<td>∆E*</td>
<td>1.30</td>
</tr>
</tbody>
</table>

The significance of ∆E*, by being characterized by a positive value, confirms that exists a difference of color between the samples printed with synthetic paste and the ones printed with natural paste. Meanwhile, the value of ∆L* indicates a slightly lighter color in the case where it was employed the synthetic printing paste, due to the fact that the sample was subjected to high temperatures in the binder curing phase.

3.3. Fastness of prints
The characterization of the printed cotton through laundering and rubbing fastness can be seen in Table 4. The fastness results indicate similar values for both types of printed fabrics and confirm the applicability of this natural pigment in the natural and synthetic printing processes. The washing
fastness, in terms of staining, revealed the same value for both tested cases, 4-5, which means relatively no staining. Meanwhile, the change in color parameter exposes a difference between the printing processes, with a higher resistance to laundering of the cotton printed with the synthetic paste. The rubbing fastness results reveal good to excellent behavior of the cotton printed fabrics.

Table 4. Fastness properties of cotton printed fabrics with synthetic and natural paste

<table>
<thead>
<tr>
<th>Laundering fastness at 25 °C</th>
<th>PE with synthetic paste</th>
<th>PE with natural paste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in color</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wool</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Acrylic</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Polyester</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Polyamide</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Cotton</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Acetate</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Rubbing fastness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet staining</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Dry staining</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

1-Very poor 2-Poor 3-Moderate 4- Good 5- Excellent

4. Conclusions
Having as a starting point the hypothesis that the natural dyes are not common to be used in a printing process, this study aimed to validate the employment of algal pigments in the mentioned process, by applying natural and synthetic printing processes.

The printing process results are visualized as pink color fixed uniformly on one side of the cotton fabrics, in both synthetic and natural processes analyzed.

The coloring tests highlighted the applicability of the phycoerythrin in the printing process, without being dependent on the nature of the paste components, natural or synthetic. The resulting colors were defined as light pink colors due to the low pigment concentration employed in the textile finishing process, so it can be affirmed that the algal colorant concentration added to the mother paste, is directly proportional to the intensity of the resulting color. In terms of the printed fabrics brightness, it was observed that the curing temperature of the binder employed in the synthetic paste composition generates a slight decrease in color intensity.

The laundering and rubbing fastness revealed good to excellent results in the printing of cotton with pigments obtained from algal biomass, in both analyzed cases, natural and synthetic printing pastes. As algal biomass represents one of the resources with the highest availability in nature, and the cultivation process for industrial purposes does not generate the pollutants emitted by the production and employment of the synthetic colorants. Hence, it can be affirmed that the sustainability and durability concept, in terms of environmental protection, is applied. Nonetheless, by employing algal sourced pigments, the final textile product is charged with the added value necessary in an eco-aware society.

Acknowledgements
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References


The life cycle assessment of cellulose pulp from waste cotton via the SaXcell™ process.

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Abstract. Recycling of cotton waste into high value products is a longstanding goal in textile research. The SaXcell™ process provides a chemical recycling route towards virgin fibres. In this study a Life cycle assessment (LCA) is conducted to measure the impact of the chemical recycling of cotton waste on the environment. Pure cotton waste and cotton containing 10 % of polyester are elaborated. The results show that chemical recycling via the SaXcell™ process can have a lower impact on climate change and other impact category than comparable pulping technologies.

1. Introduction
Recycling is one of the most important solutions to the environmental problems that the world will face due to increasing population and welfare [1]. While in the plastic and paper industry recycling is state of the art, the recycling of textiles is still underdeveloped and most of the textile waste is burned. Considering the enormous needs for energy and chemicals during the production of textile fibres [2], the creation of a closed material cycle for textile fibres is expected to decrease the environmental impact of textiles.

SaXcell™ (Saxion and cellulose) is a regenerated cellulosic fibre made out of 100 % cotton waste material and has recently been developed at Saxion UAS, The Netherlands. A lot of progress is made in creating a sustainable and economically valuable process for waste cotton recycling into regenerated cellulose fibres [3] (see Figure 1). In order to be able to give objective information on the environmental impact of the production of the SaXcell™ fibre, as a first step, a life cycle assessment (LCA) has been carried out of the dissolving pulp production from cotton waste as feedstock (figure 1 steps 1-5).

The goal of this LCA-study is to evaluate the environmental impact of the production of cellulose dissolving pulp via the SaXcell™ process. Pulp from two different kinds of (sorted) waste textiles is inventoried:

1. 100 % cotton
2. 90 % cotton / 10 % PET

Calculations are performed on processes that were not optimized for a low environmental impact.
2. Methods
The LCA study is executed by CE Delft according to the ISO-standard of good LCA practice (ISO 14044:2006 ‘Environmental management - Life cycle assessment - Requirements and guidelines’) and also reported accordingly. This investigation is a cradle-to-gate investigation, meaning that the product is evaluated from the resource extraction (cradle) to the factory gate (i.e., before transport of the pulp to the fibre production facility).

The data for the production of SaXcell pulp is collected by Saxion in consultation with textile production experts. The data is inventoried per 100 kg of SaXcell pulp. For the LCA of regenerated pulp from cotton waste, data from laboratory and pilot plant scale experiments at Saxion are used and translated to an industrial scale production. This translation is done based on literature data and experts estimations. De data is modelled in the LCA software Simapro, by making use of the environmental background data of the Ecoinvent database.

The SaXcell pulp is a feedstock for fibre production via the Lyocell process. Due to the unavailability of data on industrial fibre production via the Lyocell process, the fibre production is excluded in this study (step 6 in Figure 1).

The ReCiPe method (midpoint level) is selected as life cycle impact assessment method. With this method, eighteen different environmental effects and indicators are calculated. The results of five are shown in this report. As representative values, here, the climate change values in kg CO₂-eq. are reported. Additionally a comparison between SaXcell pulp from 100 % white cotton waste and existing sulphate pulps will be shown. Several other environmental assessments have been applied (not reported here) in order to ensure optimal comparability with other studies.

**Figure 1.** The SaXcell™ recycling process and subsequent fabric production
3. Results

3.1 Data collection (inventory)
Data about the SaXcell™ process was collected based on laboratory and pilot scale experiments and translated to an industrial scale production.

3.1.1. Energy
The (estimated) energy requirement for pulp production at industrial scale is shown in table 1. Electricity consumption in the pulping process consists of unravelling the textile waste, milling, dewatering and stirring during the chemical processes. Heat from natural gas is required for process water heating. The process is based on an integrated plant where pulp production is directly followed by fibre production (not included in this study). For that reason for drying no electricity or heat is accounted.

<table>
<thead>
<tr>
<th>Process</th>
<th>100% cotton</th>
<th>90% cotton / 10% PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (kWh)</td>
<td>58.4</td>
<td>63.8</td>
</tr>
<tr>
<td>Heat (MJ)</td>
<td>169</td>
<td>427</td>
</tr>
</tbody>
</table>

The stirring process and all heating processes are assumed to consume 30% less energy than in the lab scale situation. This was an estimation based on the effects of process optimization, integration, and up-scaling.

An uncertainty assessment is performed for the process step that adjusts the degree polymerisation (DP reduction step; see figure 1, step 5). This step was additionally calculated with the use of a biocatalyst instead of an acid as catalyst. In that case only 58 MJ instead of 169 MJ for heating was required.

3.1.2 Transport
Transport of waste material is based on averaged distances between the place of collection of textiles and the sorting facilities within the Netherlands. For the transport from the sorting location to the pulp production plant it is assumed that the pulp production takes place in the centre of the Netherlands and sorting occurs within the Netherlands (see table 2).

<table>
<thead>
<tr>
<th>Process</th>
<th>Kilometres</th>
<th>Transportation type</th>
</tr>
</thead>
<tbody>
<tr>
<td>From collection to sorting location</td>
<td>75</td>
<td>Truck (&lt;10 t)</td>
</tr>
<tr>
<td>From sorting to pulp and filament production</td>
<td>200</td>
<td>Truck (24 t)</td>
</tr>
</tbody>
</table>

3.1.3 Input materials
The chemicals used during the pulping process are given in table 3. The water consumption is a summary of the process steps and the washing cycles. It is assumed that a water recycling system reduces the actual water consumption by 70% (this is taken into account in the figures in table 3).
### Table 3. Chemicals and water input on industrial scale (per 100 kg of SaXcell pulp)

<table>
<thead>
<tr>
<th>Material</th>
<th>100 % cotton</th>
<th>90 % cotton / 10 % PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (l)</td>
<td>1500</td>
<td>2700</td>
</tr>
<tr>
<td>Sodium hydroxide pellets (kg)</td>
<td>1.6</td>
<td>15.1</td>
</tr>
<tr>
<td>Sulfuric acid (96%) (kg)</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

3.1.4 Wastewater
The pulp production generates wastewater, in similar amounts of the water used (see table 4). This wastewater contains substances as sodium sulphate and organic compounds (such as glucose and ethylene glycol). The wastewater is discarded through the sewers to a wastewater treatment plant (WWTP).

### Table 4. Waste water production on industrial scale (per 100 kg of SaXcell pulp)

<table>
<thead>
<tr>
<th>Material</th>
<th>100 % cotton</th>
<th>90 % cotton / 10 % PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste water generated (l)</td>
<td>1500</td>
<td>2700</td>
</tr>
</tbody>
</table>

3.2 Environmental impact results (selection)

3.2.1 Impact on climate change
The results for the impact on climate change for different textile wastes and processes are shown in table 5. Existing LCA studies for pulping processes reported climate change values of 0.54 - 1.34 kg CO₂-eq. for different pulps depending on quality and feedstock, which in most cases is wood.

The SaXcell™ pulping processes based on 100 % white cotton waste has an impact on climate change of 0.48 kg CO₂-eq. The use of a biocatalyst in the DP reduction step reduces the impact to 0.39 kg CO₂-eq. The impact of the bio-catalytic process is generally small, due to the catalyst itself, but also due to the milder process conditions.

A sensitivity assessment is performed on the application of ‘green’ electricity use (from sustainable sources) for the production of pulp on industrial scale. Whereas in the base analysis, all electricity used consisted of the average Dutch electricity mix, in the sensitivity assessment electricity from sustainable sources only is applied (for instance generated by solar or wind power on the production site). When only green energy sources are used, the climate impact decreases from 0.48 kg CO₂-eq to 0.27 kg CO₂-eq.

Dissolving pulp form textile wastes with PET content has a higher impact on climate change (0.86 kg CO₂-eq.) than pulp based on 100 % cotton waste (0.63 kg CO₂-eq when green energy is used). This is due to the use of more process chemicals and the need for additional processes for the separation of PET from cellulose.
**Table 5.** The impact on climate change for 1 ton of SaXcell™ dissolving pulp using different production parameters.

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Climate change (kg CO₂-eq.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 % cotton waste</td>
<td>0.48</td>
</tr>
<tr>
<td>100 % cotton waste (biocatalyst)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.39</td>
</tr>
<tr>
<td>100 % cotton waste (green energy)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.27</td>
</tr>
<tr>
<td>90 % cotton / 10 % PET</td>
<td>0.86</td>
</tr>
<tr>
<td>90 % cotton / 10 % PET (green energy)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.63</td>
</tr>
<tr>
<td>Existing pulping processes&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.54 – 1.34</td>
</tr>
</tbody>
</table>

<sup>1</sup> During the process biocatalyst are used instead of acids for reduction of the degree of polymerization.

<sup>2</sup> Green energy sources are used instead of the EU energy mix for calculation.

<sup>3</sup> Based on environmental data of pulp types available in the Ecoinvent Database [4].

3.2.2 Comparison between SaXcell pulp and sulphate pulp from different sources in five impact categories

SaXcell pulp form 100 % white cotton waste is additionally compared to existing sulphate pulps from different feedstocks. Table 6 shows that next, to the impact on climate change, SaXcell pulp shows much lower impact values than existing sulphate pulps also for human toxicity and water depletion. The most remarkable difference is found for the agricultural land occupation. Here, the traditional sulphate pulp showed the highest impact values of 4.8 m²a and the sulphate pulp from sustainable forestry gave still an impact value of 0.83 m²a. The impact value of the SaXcell pulp however, is almost negligible (0.01 m²a), caused by the fact that recycling processes do not require the cultivation of trees or plants.

**Table 6.** Comparison between SaXcell pulp and sulphate pulp

<table>
<thead>
<tr>
<th>Impact categories</th>
<th>SaXcell 100 % cotton</th>
<th>Sulphate pulp</th>
<th>Sulphate pulp sustainable&lt;sup&gt;4&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change (kg CO₂ eq)</td>
<td>0.48</td>
<td>0.54</td>
<td>0.58</td>
</tr>
<tr>
<td>Human toxicity (kg 1,4 DB eq)</td>
<td>0.107</td>
<td>0.234</td>
<td>0.194</td>
</tr>
<tr>
<td>Agricultural land occupation (m²/a)</td>
<td>0.01</td>
<td>4.82</td>
<td>0.83</td>
</tr>
<tr>
<td>Urban land occupation (m²/a)</td>
<td>0.004</td>
<td>0.031</td>
<td>0.005</td>
</tr>
<tr>
<td>Water depletion m³</td>
<td>0.0100</td>
<td>0.0170</td>
<td>0.0251</td>
</tr>
</tbody>
</table>

<sup>4</sup> pulp made of eucalyptus wood from sustainable forest management

4. Conclusions

The data and results show that dissolving pulp from white 100 % cotton textile waste has generally a low impact on climate change. This impact on the environment can additionally be decreased by the use of a biocatalyst and/or green energy sources in the production process. When the textile waste contains PET, the use of process chemicals increases and so does the impact on climate change (and other environmental effects). However, especially SaXcell pulp from 100 % white cotton shows big advantages compared to sulphate pulp in the impact categories human toxicity, urban land occupation, water depletion and a large advantage in the impact category agricultural land occupation. From this it can be concluded that the use of cotton waste as pulp feedstock for regenerated cellulose fibres has clear advantages compared to most pulp qualities in terms of most impact categories investigated in this study.
Acknowledgments
The authors wish to thank TechForFuture, Centre of Expertise HTSM (http://www.techforfuture.nl) and C&A foundation for their financial support.

References
[4] Ecoinvent database v.3.1 2014 (Dübendorf: Swiss Centre for Life Cycle Inventories)
Investigation some characteristics of chicken feather’s rachis

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Abstract: In recent years, obtaining the natural protein fibers from chicken feathers, which are obtained as a by-product in the production of chicken meat and which cause environmental pollution and important part is waste, has been drawn to the perspective of scientists. So, the investigations about the chicken feather fibers reveal important properties of these fibers. Chicken feather fibers are obtained by mechanical cutting of the barbs which have fibrous structure, the structure branched from rachis and constitute the body of the feather. The rachis part of chicken feather constitutes approximately half of the weight of the feathers. So, it is necessary to examine the properties of the chicken feathers in order to gain their industrialization. This study is concerned with the mechanical and physical properties of the material that is taken as a by-product in the production of fibers from chicken feathers and constitutes the rachis part of the feathers.

1. Introduction

In recent years, the perspective of obtaining the natural protein fibers from chicken feathers which are obtained as a byproduct in the production of white meat and the important part is waste and causes environmental pollution, attracts the attention of scientists. Investigations on chicken feather fibers reveal important properties of these fibers [1]-[4]. Chicken feather fibers are obtained by mechanical cutting of barbs (fibrous structure), which are extended from rachis. But today, technology of fiber production from chicken feathers is not available. Such a technology is being developed at Erciyes University (Turkey). In the production of fibers from chicken feather with using special machine, the rachis part of feather is seperated from this part of the barbs.

Chicken feather barbs constitutes approximately half of the weight of the feathers. This means that industrialization of chicken feathers should be considered about the part of the rachis. In this study, some properties of this material were examined.

2. Experiment

2.1. Material

The material of chicken feather’s rachis used in this study was taken from “Tad Plıç” company and obtained this chicken feathers at Textile Engineering Department in Erciyes University. The chicken feathers obtained from farm were washed at 40°C with washing matter, which has a dirt and grease remover specialities, and sodium hypochlorite(NACIO) in terms of not damaging the fibers. After the water of feathers was taken in the centrifuge, the feathers were dried at a temperature of 40°C in a laboratory-type feather dry machine at Erciyes University Department of Textile Engineering and disinfection was applied for 12 minutes at 70°C temperature. The dried feathers were subjected to the process of separation from the rachis part of the barbs part. Separated fibers and barbs were collected separately (Figure 1).

2.2. Method

Sem analyze

One of the important features of the chicken feather’s rachis material is related to the internal structure of this material. The Leo440 Scanning Electron Microscope(SEM) at Erciyes University Technology Research and Application Center was used to analyze the internal and surface of rachis. The rachis was obtained with separation of barbs was cutten precisely with the help of a sharp razor
on a glass plate in transverse and longitudinal directions and affixed on metal plates with double sided tape. Samples were subjected to SEM analysis.

**Figure 1.** Fiber (a) and rachis (b) materials taken in chicken feather fiber production

**Mechanical properties of chicken feather’s rachis**

Chicken feather is very different in terms of content of rachis material. Thus, the parts of the rachis are very different according to their thickness and length and this situation affects their mechanical properties. In order to investigate the mechanical properties of chicken feather’s rachis material, tensile tests were applied to rachis samples at Erciyes University Technology Research and Application Center. For the test, 14 rachis samples with a length over 2cm were taken and their thicknesses were measured. The thickness of the sample was measured at three points: both ends and midpoints of samples were measured with calipers and obtained average value and numbered the samples. Tensile tests were applied for each sample and all data were taken to the table.

**Investigation of the hygroscopic properties of the samples**

The hygroscopic properties of the rachis samples obtained from chicken feather were investigated as the dehumidification and water absorption properties of the samples.

**Investigation of the getting moisture ability of chicken feather’s rachis from air**

An experimental study was conducted to investigate the getting moisture ability of chicken feather’s rachis and the weighing method was used to determine the moisture content of the rachis. The ambient temperature and the relative environment humidity were chosen as the independent changing factors in the study. The levels of change of the factors are given in Table 1.

**Table 1.** Test conditions for examining the getting moisture ability of chicken feather rachis from air

<table>
<thead>
<tr>
<th>Independent changing factors</th>
<th>Change levels of factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment temperature, °C</td>
<td>20  40  60</td>
</tr>
<tr>
<td>Relative environment humidity, %</td>
<td>65  80  95</td>
</tr>
</tbody>
</table>

For using in the experiments, the 3gr sample was taken from rachis mass, which was conditioned for 2 hours at 20°C temperature and 65% relative humidity. The samples were weighed for 2 hours under the conditions specified in the test plan and the weights of the samples were determined by weighing and the results were written to the table. The moisture of the fiber sample which was kept for 2 hours under the determined environment conditions according to the test plan was evaluated in terms of the dry weight of the sample in percent, as following the formula:
In this formula, \( W \) - moisture content sample according to dry weight - (%), \( m_{\text{wet}} \) - wet weight of sample (g), \( m_{\text{dry}} \) - dry weight of sample (gr).

To determine dry weight of fiber sample were kept under normal conditions (20°C temperature and 65% relative humidity) for 2 hours and taken 3g fiber from sample. Then, this fiber was kept for 120 minutes at 105°C. At the end of the period, rachis mass was measured and the sample dry weight was found to be 2.72gr.

The moisture that chicken feathers get from the air was determined by weighing by keeping under the different environmental conditions specified in Table 1 and the percent of dry weight of the sample was calculated and the results were written to the table. For the test results, two-directional ANOVA was applied with Minitab 17 program package.

Investigation of water absorption ability of chicken feather’s rachis

Water-soaked chicken feather’s rachis were tested to determine how much water was retention of structure. To determine water absorption properties of chicken feather rachis, the “Water Immersion Method” was based on which is proposed by the standard of TS 866 “Determination of Water Absorption Properties of Cotton Textile Products” . Because of the material to be tested, chicken feather’s rachis is not a standard material, it has to adapt to the standard’s requirements to the test object. Test samples were prepared as follows: samples were conditioned according to TS 240 and weighed 3g and placed in the sample bag. During the experiment, the special experimental setup, it was prepared to immerse the samples in the water. The fibers, which was weighed as 3gr, were placed in the strainer apparatus, and the apparatus was placed in a 2lt glass beaker. Distilled water, which was a 21±3°C, was added to the beaker. Filter apparatus was designed so that it can be hanged in the middle of the beaker. The apparatus was suspended in water and the stopwatch was turned on by placing it in a test cabinet designated for the required level of temperature. At the end of the 30, 90, 150 minutes’ period, the apparatus was removed from the water, and it was suspended for 10 minutes in order to remove the water, which is mechanically related to the rachis by filtration. The sample was weighed on the precision scale.

At the end of the experiment, the values, which are related the weight of the weighed fibers, were written in table. The experiment was repeated at 20°C, 40°C, and 60°C temperature for each rachis. New rachis was used for each time.

For the test results, two-directional ANOVA was applied with Minitab 17 program package. For the independent variables, water temperature and water immersion time were accepted (Table 2).

<table>
<thead>
<tr>
<th>Independent changing factors</th>
<th>Change levels of factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water temperature, °C</td>
<td>20 40 60</td>
</tr>
<tr>
<td>The water’s remaining time in the water, minute</td>
<td>30 90 150</td>
</tr>
</tbody>
</table>

3. Result and Discussion

Structural properties of chicken feather’s rachis material

The length of the rachis material obtained from the chicken feather is variable. For crude feathers, rachis size is the length of the feather. However, since rachis is broken during the fiber Production from feathers, this length varies widely. In our studies, the length of the rachis pieces ranged from 5 to 60mm and the thickness ranged from 0.5 to 1.8mm.

The tensile test results applied to the chicken feathers’ rachis samples are shown in Table 3. For the test, 14 sample was taken and applied to the tensile test and the breaking strength, the breaking
extension and elastic modulus values are written in accordance with thickness values of the samples. As can be seen here, there is a close relationship between the tensile strength and the thickness of the rachis material. The mean values of the mechanical properties are given in Table 3.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Diameter of rachis sample, (10^{-3}) m</th>
<th>Max Strength, N</th>
<th>Max Extension, %</th>
<th>Elasticity modulus, 100-MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,25</td>
<td>45,81</td>
<td>4,88</td>
<td>9,96</td>
</tr>
<tr>
<td>2</td>
<td>1,33</td>
<td>64,66</td>
<td>8,44</td>
<td>8,04</td>
</tr>
<tr>
<td>3</td>
<td>1,07</td>
<td>27,06</td>
<td>3,79</td>
<td>8,77</td>
</tr>
<tr>
<td>4</td>
<td>1,32</td>
<td>54,62</td>
<td>7,51</td>
<td>10,76</td>
</tr>
<tr>
<td>5</td>
<td>1,40</td>
<td>76,25</td>
<td>9,79</td>
<td>8,14</td>
</tr>
<tr>
<td>6</td>
<td>1,69</td>
<td>82,71</td>
<td>5,01</td>
<td>10,17</td>
</tr>
<tr>
<td>7</td>
<td>1,52</td>
<td>80,83</td>
<td>9,17</td>
<td>8,23</td>
</tr>
<tr>
<td>8</td>
<td>1,37</td>
<td>59,70</td>
<td>7,22</td>
<td>9,01</td>
</tr>
<tr>
<td>9</td>
<td>1,47</td>
<td>73,23</td>
<td>10,19</td>
<td>8,23</td>
</tr>
<tr>
<td>10</td>
<td>1,34</td>
<td>56,58</td>
<td>4,68</td>
<td>11,40</td>
</tr>
<tr>
<td>11</td>
<td>1,22</td>
<td>37,34</td>
<td>4,55</td>
<td>9,07</td>
</tr>
<tr>
<td>12</td>
<td>1,39</td>
<td>39,33</td>
<td>3,93</td>
<td>8,94</td>
</tr>
<tr>
<td>13</td>
<td>1,12</td>
<td>34,56</td>
<td>5,22</td>
<td>9,33</td>
</tr>
<tr>
<td>14</td>
<td>1,16</td>
<td>37,48</td>
<td>3,67</td>
<td>11,65</td>
</tr>
<tr>
<td>Average value</td>
<td>1,33</td>
<td>55,01</td>
<td>6,25</td>
<td>9,41</td>
</tr>
</tbody>
</table>

The specific weight of chicken feather material is known as 0,80g/m³ [2]. According to measurement of volumetric weight of rachis is 0,255g/m³ in our study.

One of the most important features of the feathers is that they are extremely light, which is due to the hollow structure of the feather material. Through SEM analysis, micro-porous microstructure of chicken feather bars and rachis were obtained and is was seen that this structure was similar to each other (Figure 2).

![Figure 2. SEM images of the microcellular internal structure of chicken feather fiber and rachis](image)

In Figure 3, SEM images of transverse and longitudinal sections of rachis samples are given. It has been revealed that the pores forming this structure are in the form of microcells with dimensions of 5…20 µm, which are closed on all sides.
Examination of hygroscopic properties of chicken feather rachis

The experimental results of examination of the getting moisture ability of chicken feather’s rachis are given in Table 4.

Table 4. Test results of dehumidification ability of rachis

<table>
<thead>
<tr>
<th>Experiment number</th>
<th>Environment temperature, °C</th>
<th>Relative humidity of the environment, %</th>
<th>Moist weight of rachis mass, gr</th>
<th>The moisture content of the sample according to dry weight, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>65</td>
<td>3,00</td>
<td>10,29</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>80</td>
<td>3,16</td>
<td>16,18</td>
</tr>
<tr>
<td>3</td>
<td>95</td>
<td>3,20</td>
<td>17,65</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>3,07</td>
<td>12,87</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>40</td>
<td>3,08</td>
<td>13,24</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>95</td>
<td>3,25</td>
<td>19,49</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>65</td>
<td>2,86</td>
<td>5,15</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>60</td>
<td>2,94</td>
<td>8,09</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>60</td>
<td>3,09</td>
<td>11,76</td>
<td></td>
</tr>
</tbody>
</table>

For the values in Table 4, two-directional ANOVA was applied with Minitab 17 program package and results were written to the Table 5a. According to these results, the moisture content of the sample for different humidity and temperature environment is significant.

In Figure 4a graphical curves are given which express the between the moisture content of test samples according to the dry weight and relative humidity of environment.

As can be seen from these curves, the ability of rachis to absorb moisture from air varies according to environment conditions. Amount of moisture the material is receiving from the air increase with the increasing of relative humidity of environment. This increase continues until 40°C.

At the temperature of 60°C, humidity of the rachis from the air is lower than the humidity rate of 20°C and 40°C temperature. This is a result of the activation of water molecules by increasing the temperature. As the humidity increases, dissolved bonds among the macromolecules increase. As the environment humidity increase, the rachis continues to take moisture from the air. However, as the water molecules become more active by increasing the temperature, the moisture amount of rachis is not much.

Examination of water absorption ability of chicken feather rachis
Water absorption test results of water-dipped chicken feather’s rachis are shown in Table 6. In Table 5b gives the variance analysis applied to these results. In Figure 4b, according to the table values, when compared the water amount of rachis material according to dry weight with water immersion time of samples, the graphical curves are given. These curves show that water absorption ability of rachis material changes according to water absorption time and water temperature in a certain way.

### Table 5. ANOVA tables of dehumidification test results of rachis

<table>
<thead>
<tr>
<th>a) General Linear Models HRS versus RHE; ET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
</tr>
<tr>
<td>Factor coding (-1; 0; +1)</td>
</tr>
<tr>
<td>Factor Information</td>
</tr>
<tr>
<td>Factor Type Levels Values</td>
</tr>
<tr>
<td>RHE  Fixed 3 65; 80; 95</td>
</tr>
<tr>
<td>ET  Fixed 3 20; 40; 60</td>
</tr>
<tr>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>Source  DF  Adj SS  Adj MS  F-Value  P-Value</td>
</tr>
<tr>
<td>RHE 2  79,725  79,725  63,714  0,001</td>
</tr>
<tr>
<td>ET 2  76,988  39,990  63,57  0,001</td>
</tr>
<tr>
<td>Error 4  3,430  0,861</td>
</tr>
<tr>
<td>Total 6 154,733</td>
</tr>
<tr>
<td>Model Summary</td>
</tr>
<tr>
<td>S R-sq R-sq(adj) R-sq(pred)</td>
</tr>
<tr>
<td>0,770226  95,444  95,444  95,444</td>
</tr>
<tr>
<td>Coefficients</td>
</tr>
<tr>
<td>Term  Cost  SE Cost  T-Value  P-Value  VIF</td>
</tr>
<tr>
<td>Reference  12,338  0,293  41,48  0,000</td>
</tr>
<tr>
<td>RHE 65  2,901  0,361  7,97  0,001  1,35</td>
</tr>
<tr>
<td>ET 30  1,143  0,266  3,12  0,036  1,33</td>
</tr>
<tr>
<td>Regression Equation</td>
</tr>
<tr>
<td>HRS = 2,901 RHE,65 - 1,143 ET,30 + 3,430 ET,60</td>
</tr>
<tr>
<td>b) General Linear Model: HRS versus WPS; T</td>
</tr>
<tr>
<td>Method</td>
</tr>
<tr>
<td>Factor coding (-1; 0; +1)</td>
</tr>
<tr>
<td>Factor Information</td>
</tr>
<tr>
<td>Factor Type Levels Values</td>
</tr>
<tr>
<td>WPS  Fixed 3 30; 60; 150</td>
</tr>
<tr>
<td>T  Fixed 3 20; 40; 60</td>
</tr>
<tr>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>Source  DF  Adj SS  Adj MS  F-Value  P-Value</td>
</tr>
<tr>
<td>WPS 2  797,7  379,87  6,89  0,005</td>
</tr>
<tr>
<td>T 2  2125,2  1064,12  21,99  0,008</td>
</tr>
<tr>
<td>Error 4  429,5  54,99</td>
</tr>
<tr>
<td>Total 6 3105,9</td>
</tr>
<tr>
<td>Model Summary</td>
</tr>
<tr>
<td>S R-sq R-sq(adj) R-sq(pred)</td>
</tr>
<tr>
<td>0,41643  92,751  92,751  92,751</td>
</tr>
<tr>
<td>Coefficients</td>
</tr>
<tr>
<td>Term  Cost  SE Cost  T-Value  P-Value  VIF</td>
</tr>
<tr>
<td>Reference  7,41643  92,751  92,751  92,751</td>
</tr>
<tr>
<td>WPS 30  11,64  3,56  3,33  0,029  1,33</td>
</tr>
<tr>
<td>T 30  -19,78  3,56  -5,53  0,05  1,33</td>
</tr>
<tr>
<td>40  19,67  3,56  5,53  0,004  1,33</td>
</tr>
<tr>
<td>Regression Equation</td>
</tr>
<tr>
<td>X = 313,43 + 11,64 WPS,30 - 16,78 WPS,40 +</td>
</tr>
<tr>
<td>- 0,16 WPS,150 + 0,12 WPS,20 + 20,47 WPS,60</td>
</tr>
<tr>
<td>- 20,58 WPS,40</td>
</tr>
</tbody>
</table>

Notes: HRS – Humidity ration of sample; RHE – Humidity of environment, ET – Environment Temperature, WPS – The wetting period of the sample, T – Temperature

![Figure 4](image_url)

**Figure 4.** Changing in the rate of dehumidification in chicken feather rachis according to environment humidity

As can be seen from graphs in Table 5 and Figure 6, the amount of water retained in the structure of sample between 20-60°C temperature, which are tested to the getting water test for 30, 60, and 150 minutes, is decreasing at the first time with increased water-dip time in constant environment temperature.
The reason for this is that the rachis pores are initially filled with air and the water molecules have difficulty to reaching these pores. As the temperature increases, the pores which are abandoned by the air molecules are trapped with water molecules because of the increasing activity of the air molecules and water molecules and consequently water content in rachis increase. However, this situation changes over 40°C. Some of the water molecules, which are sufficiently activated, leave some pores. At 60°C, even if the process takes place at temperature like between 20 and 40°C, because of the high activity of the water molecules, rachis retains less water in structure.

<table>
<thead>
<tr>
<th>Experiment number</th>
<th>Temperature, °C</th>
<th>The wetting period of the sample, minute</th>
<th>Wet weight of rachis, gr</th>
<th>The moisture content of the rachis according to dry weight, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>30</td>
<td>12.05</td>
<td>343.01</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>12.54</td>
<td>361.03</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>11.68</td>
<td>329.41</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>14.94</td>
<td>449.26</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>60</td>
<td>9.94</td>
<td>265.44</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>10.68</td>
<td>292.65</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>150</td>
<td>8.62</td>
<td>216.91</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>150</td>
<td>10.74</td>
<td>294.85</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>60</td>
<td>11.26</td>
<td>313.97</td>
<td></td>
</tr>
</tbody>
</table>

4. General Results

In this study, some properties of rachis material, geometric, mechanical and hygroscopic properties have been examined. In our studies, the length of the rachis pieces ranged from 5 to 60mm and the thickness ranged from 0.5 to 1.8mm. The measured volumetric weight of rachis is 0.255g/m³. The average breaking strength of the rachis pieces is 55.01N, the maximum extension at break time is 6.25%, elasticity modulus is 941 MPa. The internal structure of rachis has been examined and it has been revealed that this structure is in the form of 5-20 μm micro cells. These construction signifies the lightness and good insulation properties of rachis.

It has been found that the rachis material has high hygroscopy. The moisture absorbance ability of this material was investigated according to the environment temperature and the relative humidity of environment and there was a statistically significant relationship between these indicators. Rachis material has also water absorption properties. This characteristic of rachis was investigated according to water temperature and duration of interacting with water and it was found that there was a statistically significant relation between these parameters. The results will allow for new areas for use rachis material.

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References


Multiple faces of contemporary hand knitting

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Abstract. Knitting and crocheting are traditional textile techniques with great significance both in history and modern times. Similar to other textile techniques, knitting has developed into a diversified industrial sector, comprising the production of knitted fabrics, knitwear, hosiery and fashion accessories. At the same time, contemporary knitting and crocheting became hobbies as well as arts-and-crafts activities, extending to various areas of work and leisure. Historical and traditional ethnic knitting and crocheting patterns keep inspiring designers’ collections and also other industrial products. Not so long ago, knitting was seen as an ordinary and unchanging indoor activity and, in its domestic history, it was the preserve of older women making products of dainty work and taste. Today, knitting deals with urban population of all classes. The popularity of leisure hand knitting is increasing; moreover, hand knitting is becoming more and more widespread among young people. With the emergence of artistic and handicraft markets, hand-knitting and crocheting developed into a profitable market activity. Positive effects of hand knitting have become increasingly important - from generating creativity and innovativeness, through knitting and socializing in groups, to medical and therapeutic effects as well as social and global connections. Yarn bombing, yarn storming or graffiti knitting has been used to describe urban social practices of knitted objects placed, or tagged, in public spaces. Knitting became means of communication, artistic and social expression and statement. The advantage of hand knitting is its mobility. One can knit almost everywhere, and for hand knitting, only a ball of yarn and knitting needles are required. Hand-knitted products have nice touch, they are custom-made and therefore personalized.

1. Introduction

Knitting and crocheting are traditional textile techniques with great significance both in history and modern times. Similar to other textile techniques, knitting has developed into a diversified industrial sector, comprising the production of knitted fabrics, knitwear, hosiery and fashion accessories for clothing as well as for non-clothing purposes. At the same time, contemporary knitting and crocheting became hobbies as well as means of artistic expression and arts-and-crafts activities, extending to various areas of work and leisure. Historical and traditional ethnic knitting and crocheting patterns keep inspiring designers’ collections and also other industrial products.

Not so long ago, knitting was seen as an ordinary and unchanging indoor activity and, in its domestic history, it was the preserve of older women making products of dainty work and taste [1]. Today, knitting deals with rural and urban population of all classes. The popularity of leisure hand knitting and crocheting is increasing; moreover, hand knitting is becoming more and more widespread among young urbans. With the emergence of hobby and artistic handicraft markets, hand-knitting and crocheting developed into a profitable market activity.
Positive effects of hand knitting have become increasingly important - from generating imagination, creativity and innovation, even humor, through knitting and socializing in groups, to medical and therapeutic effects as well as trade, social and global connections. Knitting became means of communication, artistic and social expression, statement, trend, way of life.... The advantage of hand knitting are its flexibility and mobility. One can knit almost everywhere, at home, in a park, in a café or public transportation. For hand knitting, only a ball of yarn and knitting needles or a crochet are required. Hand-knits are colorful, they have a nice touch, they can be 3D knitted/shaped, they are custom-made and therefore personalized.

2. Leisure knitting and knitting in groups
In the last decade, there has been a resurgence of interest in knitting as a form of leisure. From ‘stitch n bitch’ groups and pub knitting circles to fiber festivals and knit meets, new public sites for participating in knitting have emerged as part of a contemporary craft movement. Accompanying this renaissance is a growing presence of “craftsters” on the web, with blogs, podcasts, social networking sites and folksonomies like Flickr and YouTube connecting a global community of knitters and providing them with a wealth of resources and support. Knitters photograph and blog about their projects and yarns, chat and plan face-to-face knit festivals via forums, search for podcasts to learn new skills, follow “celebrity” knit bloggers and sell and exchange patterns and yarn via knitting networking sites [2].

Figure 1. Hand knitting at Abilmente hobby fair (Vicenza, Italy 2015)
The growth of do it yourself (DIY) craft culture, of which knitting is a part, itself has a history that encompasses professional and leisure practices, diverse forms of production and consumption, fine art, performance and fashion with activities spanning public and private spheres [2]. Knitting, along with a number of other lifestyle activities like gardening and cooking, is seen as providing an alternative temporality which allows individuals to create meaning outside of the spheres of domesticity or employment [3]. This nostalgic reclaiming of craft is understood as a response to mass consumerism, globalization and the homogeneity of the high street, reflecting a desire for individualization and a playful and ironic trend for celebrating domesticity in popular culture [4, 2]. On the other hand, it was proved that knitting in a group impacts significantly on perceived happiness, improved social contact and communication with others [5]. In 2012, Slovenian group launched the project Connections. Connections was a textile installation in progress. Project offered moments of calm engagement, creative expression, healing remembrance, relaxed socialization to regular people. Visitors were invited to take off shoes, sit down, inspect, touch, and learn simple textile technique, how to make a rug with their fingers. The project connected people by working together on the symbolic textile field – carpet [6].

![Figure 2. Group knitting with fingers: project Connections (Ljubljana, Slovenia 2012)](http://www.oloopdesign.com/en/projects/connections/)

3. Therapeutic knitting
There is increasing evidence that engaging in creative and meaningful occupation can impact positively on health and wellbeing. The results of an online survey among more than 300 knitters showed that there was a significant relationship between knitting frequency and feeling calm and happy. More frequent knitters also reported higher cognitive functioning [5]. Knitters control the rhythm of their craft and may change it according to their mood. This rhythm is instantaneously calming [7].

Therapeutic knitting takes the benefits of knitting and enhances them to improve well-being or to treat certain medical conditions. The psychological benefits of knitting alone or within a group range from distraction, refocusing of attention, and enabling feelings of control to providing rewarding occupation and enabling relaxation and contribution. Through knitting, lost emotions associated with anticipation, pride, excitement, and happiness are reawakened. Life circumstances such as illness, retirement, or redundancy can change identity and perception of self. Knitting can enable the knitter to
build a new positive identity through, for example, knitting for charity [7]. Knitting complex patterns can also be beneficial for hand joint exercise and memory training.

4. Knitting art
Because of the nature of the stitch and the use of a continuous thread, knitted fabrics are very strong and can be used to support large structures. Knitting that appears in unexpected environments, knitting that masquerades, as something it is not, knitting that provokes questions – this is when knitting becomes art [8].

The textile that had arisen as a need since the birth of humankind changed over time and managed to get out of everyday use. The knitting that takes place among the textile arts which are emerging together with the cultural history of mankind has proceeded on its way together with the growing cultures and the age without slowing down and has been used in the field of art. Contemporary artists have revealed new forms of art of knitting by getting out of traditions or by reinterpreting the traditional values [9].

For example, Sandra Backlund is a knitting artist that brings architectural forms to knitwear. Her knitted garments are more pieces of art than wearable clothes.

![Figure 3. Sandra Backlund: Ink Blot Test](http://sandrabacklund.com/previous-collection.php?page=28)

5. Guerilla knitting
Guerilla knitting also named yarn bombing, yarn storming or graffiti knitting has been used to describe urban social practices of knitted objects placed, or tagged, in public spaces. This amusing new trend encourages young urbanites to wrap colorful knitted fabric around lamp posts, trees, and sometimes
entire city buses to brighten the city environment. The fad reportedly started in Texas among young knitters seeking a creative way to use their leftover yarn and unfinished projects. It has since spread worldwide, as the “artists” photograph their installations and share them on the Internet [10]. Guerilla knitting has also spread in Slovenia. In spring 2017, Irena Erzen has dressed street trash bins in Koper and attracted much interest with her temporary urban installations.

Figure 3. Guerilla knitting by Irena Erzen (Koper Slovenia, 2017)

6. Knitting publications
The number of publications on knitting increased more than twice starting from year 2000; 462 books were published between 2000 to 2007, while only 215 were published from 1980 to 1990. These new publications offer a variety of knitting experiences from designs inspired by such staples of knitting patterning as Fair Isle and Nordic designs to books that explore knitting as therapeutic activity equal to meditation. Along with the patterns, many books provide inspirational quotes and descriptions of free flowing train of thought of a knitter while she/he works [11]. Books entitled At Knit Ends: Meditations for women who knit too much [12], Knitting Ephemera [13] or The Yarn Whisperer [14] were published in the last twelve years.

7. Conclusion
It can be concluded that the recent rise of a historical knitting technique and a hobby that was considered old-fashioned until the last few years, has become synonymous with trendy socializing and wellbeing that can reduce stress, tackle depression, contribute to pain management, enhance concentration and memory, and more [15]. Hand knitting can also be a means of art expression or activism as well as profession and a profitable activity. Hand knitting has expanded in all aspects of our lives. Based on the same interlacing principles it represents a counterweight to modern hi-tech industrial knitting.

References


Assessment of toxicity of raw textile wastewater and after its reuse

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Abstract. Five consecutive dyeings were made using the treated effluent in every step. All photochemical treatments obtained decolourization efficiency (DE) above 90%, allowing the effluent to be reused in dyeings with fluorescent brighteners, from the first until the last treated effluent. In this proposed process, the rate of total organic carbon (TOC) presented after five consecutive dyeings achieved with treated effluent was 34 mg L⁻¹ compared with 435 mg L⁻¹ of the final effluent that was obtained after five conventional processes. The salinity of the final effluent obtained by this proposed process was 2.34 g L⁻¹ of NaCl compared with 25.00 g L⁻¹ presented in the effluent obtained by the conventional process. The values of the colour fastness to water showed no significant differences between the colours that were made by two processes. The average water consumption for a one-kilogram cotton dyeing after fifteen dyeings achieved by this proposed process was approximately 24 litres compared with the 70 litres that were consumed by the conventional process. However, the final treated effluent presented values of toxicity < 6.25% (EC₅₀, with 95% confidence interval) against 10.25% of the raw effluent. It means that in the sample concentration of the treated effluent presented 100% of Daphina similis mortality, indicating that this sample was more toxic than the raw effluent.

Keywords: toxicity, reuse of water, reactive dyestuff, dyeing of cotton, textiles
1. Introduction

The reactive dyestuff, which is the primary type of dyestuff that is used in Brazil and in all over the world [1,2], contains a reactive group forming a covalent bond with the fibre polymer and acts as an integral part of the fibre. This covalent bond is formed between the dye molecules and the terminal –OH (hydroxyl) group of cellulosic fibres or between the dye molecules and the terminal –NH2 (amino) group of polyamide or wool fibres. Moreover, textile processing effluents are often characterized by a high content level of dissolved organic dyes, resulting in large values of chemical and biological oxygen demands (COD and BOD) in the aquatic systems into which they are discharged. Moreover, reactive dyeing is the most commonly used coloration method for cotton, yet, it generates the most problematic effluents that are not only difficult to treat but also non-reusable. Such wastewater streams are a major environmental issue in developing countries [3-5].

It has been studied by researchers from many countries, including various types of treatments by photocatalysis. As example, Ben Younes et al [6] investigated the ability of Trametes trogii to decolorize azo and triarylmethane-dyes in the absence of redox mediators and studied various physico-chemical parameters in order to achieve maximum dye decolorization. Xiao et al [7] investigated supported perovskite oxide (LaFeO3/SBA-15) for the first time as catalyst for the oxidation of organic dyestuff using hydrogen peroxide as oxidant, where tests indicate that LaFeO3/SBA-15 has large adsorption capacity, good catalytic performances, and wide working pH ranges (from 2 to 10) for the oxidation of dyestuff such rhodamine B, reactive brilliant red X-3B and direct scarlet 4BS.

Dias et al [8] evaluated the use of a residue-based catalyst for heterogeneous photo-Fenton of Reactive Black 5 dyestuff (RB5), preparing the catalyst by chemical vapor deposition of ethanol on a red mud residue, an important waste of the aluminum industry rich in iron oxide. Semeraro et al. [9] investigated the interactions between two industrial textile dyestuff in an aqueous solution and a series of different commercial cyclodextrins at 25 °C by spectrophotometric and electrochemical measurements to study their efficiency in the removal of colour from real textile wastewater in order to recover and reuse both clean water and dyes for other industrial processes, which is the same objective of this study.

Synthetic polyethylenimine and biopolymer chitosan were employed by Dasgupta et al. [10] in order to initiate the retention of anionic reactive red 120 (RR 120) from its aqueous solutions using polymer-enhanced ultrafiltration. In the ionizing radiation area, Borrely et al. [11] investigated colour and toxicity removal of C.I Reactive Blue 222 after radiation processing, which was conducted using a dynamiton electron beam accelerato. The best value of colour removal by radiation was 90%, with 2.5 kGy, in which Daphnia similis and Brachionus plicatilis were fitted well. All those factors mentioned before, such as water consumption, waste treatment, cotton fibre, reactive dyestuff and their effluents, were decisive for the development of this study.

2. Material and Methods

2.1. Reagents and materials

Sodium metasilicate 98% (Quimesp), nonionic detergent, nonionic levelling agent, fluorescent brightener and catalase (Golden Technology) were used in the processes of bleaching and white dyings; hydrogen peroxide 50% (Quimesp) was used in the processes of bleaching, white dyings and homogeneous photocatalysis; sulfuric acid 98% (Labsynth) was used for pH correction (Quimis pH metre); potassium titanium oxalate 0.1 mol L\(^{-1}\) (Merck) was used to detect hydrogen peroxide (H\(_2\)O\(_2\)) residuals after bleaching and photocatalysis processes.

C. I. Reactive Yellow 145; C. I. Reactive Orange 122, C. I. Reactive Red 239, Azo chromophore group, heterobifunctional reactive groups type VS+MCT, 1136.32 g mol\(^{-1}\) and CAS Registry Number 89157-03-9 (RR239) and C. I. Reactive Black 5, Azo chromophore group, homobifunctional reactive groups type VS+VS, 991.82 g mol\(^{-1}\) and CAS Registry Number 12225-25-1/17095-24-8 (RB5) were provided by Golden Technology; sodium chloride 98%, sodium carbonate 98% and sodium hydroxide 98% (Quimesp) were used in the dyeings process; 100% cotton woven fabric, 180 g m\(^{-2}\), 26 yarns 20/1 Ne per cm in the weft and 24 yarns 30/1 Ne per cm in the warp were also used.
2.2. Procedures

2.2.1. Bleaching. The bleaching process was executed in a jigger (Jigger Mathis) in 100 g samples with a liquor ratio of 10:1 using 1.0 g L\(^{-1}\) detergent; 1.0 g L\(^{-1}\) levelling agent and 0.5 g L\(^{-1}\) sodium metasilicate (Na\(_2\)SiO\(_3\)). In the case of H\(_2\)O\(_2\), bleaching was conducted with normal water with 4.0 mL L\(^{-1}\), and the bleaching achieved with reuse water was executed with \(4.0 - Q_R\) mL L\(^{-1}\), where \(Q_R\) is the residual amount of H\(_2\)O\(_2\) detected after the photochemical treatment [12]. In both cases, the substrate was treated for 30 min at 95 ºC. Then, the bath was cooled to 55 ºC, and the pH was adjusted to 6.5. After 5 min at 55 ºC, 0.5 g L\(^{-1}\) of catalase was added, and the temperature was maintained during the 15 min in order to remove residual of H\(_2\)O\(_2\). The 0.1 mol L\(^{-1}\) (C\(_4\)K\(_2\)O\(_9\)Ti) potassium titanium oxalate solution was used to detect any possible H\(_2\)O\(_2\) residual.

2.2.2. Dyeings. Five colours and their Pantone® numbers were based on the Book of SENAI Mix Design Spring/Summer 2016/2017. The dyeing recipes were obtained by Match Wizard® software (Datacolor 650 SF Plus) and are described in the Table 1.

<table>
<thead>
<tr>
<th>Color</th>
<th>Pantone®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>-</td>
</tr>
<tr>
<td>Cosmic</td>
<td>194027</td>
</tr>
<tr>
<td>Mystic</td>
<td>193323</td>
</tr>
<tr>
<td>Refugy</td>
<td>191543</td>
</tr>
<tr>
<td>Safari</td>
<td>180312</td>
</tr>
</tbody>
</table>

The Euclidian distance between the colours obtained with normal water versus the colours obtained with treated effluent was calculated by the equation

\[ \Delta E^* = \sqrt{(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2} \]

where \(a^*\) represents the green-red axis, \(b^*\) represents the yellow-blue axis and \(L^*\) represents the white-black axis.

The amount of salt (NaCl), sodium carbonate (Na\(_2\)CO\(_3\)) and sodium hydroxide (NaOH) used in all the dyeings were obtained using the manufacturer's recommendations. The only exception was the amount of NaCl that was used in dyeings made with recycled water; in these cases, the recommended amount of NaCl was subtracted from the amount that was already present and determined by conductivimetry (Digimed DM-32). These values were obtained by correlation between the specific conductivity (\(\mu S\ cm^{-1}\)) and known concentrations of NaCl. The correlation graphic and the equation are shown in Figure 1.

![Image](image_url)
The recipes are described in Table 2, including the amounts of dyestuff and auxiliaries that were utilized in all dyeings.

<table>
<thead>
<tr>
<th>Color</th>
<th>RY145</th>
<th>RR239</th>
<th>RB5</th>
<th>Base RB5</th>
<th>NaCl</th>
<th>Na₂CO₃</th>
<th>NaOH 50 °Bé</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7.000</td>
<td>70.000</td>
<td>7.000</td>
<td>2.000</td>
</tr>
<tr>
<td>Cosmic</td>
<td>0.205</td>
<td>0.366</td>
<td>3.000</td>
<td>-</td>
<td>60.000</td>
<td>7.000</td>
<td>1.500</td>
</tr>
<tr>
<td>Mystic</td>
<td>0.284</td>
<td>1.040</td>
<td>1.420</td>
<td>-</td>
<td>50.000</td>
<td>6.000</td>
<td>1.500</td>
</tr>
<tr>
<td>Refugy</td>
<td>0.700</td>
<td>1.440</td>
<td>0.300</td>
<td>-</td>
<td>50.000</td>
<td>6.000</td>
<td>1.500</td>
</tr>
<tr>
<td>Safari</td>
<td>0.950</td>
<td>0.800</td>
<td>0.680</td>
<td>-</td>
<td>50.000</td>
<td>6.000</td>
<td>1.500</td>
</tr>
</tbody>
</table>

All dyeings were executed by the “All in” process proposed by Salem [13]. The baths of every step were collected, the pH was adjusted to 7.0 (H₂SO₄), and the final effluent was stored to posterior photochemical treatment.

2.2.3. Photocatalysis treatments. The photocatalysis processes were performed in a batch reactor with a capacity of 10 L, using 3 lamps Phillips TL 8 W with irradiation type UV-C in 253.7 nm operating with 50 V, 2 A and independent actuation, setting the potency variation to 8 W, 16 W or 24 W. Circulation of the bath was provided by a 6 W pump, with a circulation capacity equal to 150 L h⁻¹.

Based on the results presented by Rosa et al. [14], the first effluent was diluted in a 4:1 ratio of water and effluent. The water in the next effluent was replaced by the previously treated effluent.

Time was maintained until a minimum of 85% of decolourization efficiency (Dₑ) was reached, as calculated by equation

\[ \% Dₑ = \left[ 1 - \left( \frac{Abs_s}{Abs_b} \right) \right] \cdot 100 \]

In order to use the absorbance decay, aliquots of 12 mL were collected in intervals of 15 min and conditioned in acrylic bucks with 1.0 cm of optical path. The absorbance (Abs) of the aliquots was assessed by spectrophotometry VIS (Konica-Minolta CM 3600d).

2.2.4. Reuse of treated effluents. The first dyeing effluent treatment was diluted in a 4:1 ratio with water. The second dyeing effluent treatment was diluted in a 4:1 ratio with the first treated effluent instead water; this process continued with the third dyeing and so on, until 15 dyeings were completed.

A white dyeing was performed in order to verify a possible interference in this type of dyeing when executed with treated effluents after treatment with each of the 15 dyeings. In addition, white dyeings were also conducted with water and compared by the whiteness index (Wi), which was determined by the Ganz-Griesser method [15] and calculated by the following equation

\[ Wi = (1 \cdot Y) + (-1868.322 \cdot x) + (-3695.690 \cdot y) + 1809.441 \]

where Y is the value of Y-tristimulus of the sample; x and y are the values of the chromaticity coordinates assessed by spectrophotometry VIS at 470 nm, under D65 illuminant at 10° (Konica-Minolta CM 3600d).

2.2.5. Colourfastness. The fastness properties of all colours were tested and assessed according to the standards described by the ISO 105-E01 Textiles from the International Organization for Standardization (ISO) [16]. All colour changes and staining were assessed by the grey scale using spectrophotometer software (Konica-Minolta CM 3600d) under illuminant D65. Before the tests, the samples were conditioned for 24 h in a standard atmosphere at 20 ± 2°C and at a relative humidity of 65 ± 2%.

2.2.6. Total organic carbon (TOC). The TOC was determined by the 5310-D/14878 method [17] after the photochemical treatment of the 5th dyeing (proposed process) and in the untreated effluent after 5th dyeings (conventional process).
2.2.7. *Toxicity*. The toxicity test for Daphnia similis was performed according to procedure described by ABNT NBR 12713/2009 norm [18]. The results, expressed in EC$_{50}$, indicate the median concentration of the effluent that caused toxic effect, or immobility, on the microorganisms exposed to the sample for 48 hours.

### 3. Results and discussion

#### 3.1. Effluents treatment

All photocatalysis treatments presented D$_E$ values higher than 90%, all of them indicating reactions of first order. The sample values are described in Table 3.

<table>
<thead>
<tr>
<th>n</th>
<th>Color</th>
<th>Abs$_a$</th>
<th>Abs$_f$</th>
<th>D$_E$</th>
<th>Time (min)</th>
<th>$\lambda_{\text{max}}$ (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1º</td>
<td>Black</td>
<td>2.3468</td>
<td>0.0003</td>
<td>99.99</td>
<td>240</td>
<td>600</td>
</tr>
<tr>
<td>2º</td>
<td>Cosmic</td>
<td>0.7943</td>
<td>0.0048</td>
<td>99.40</td>
<td>240</td>
<td>50</td>
</tr>
<tr>
<td>3º</td>
<td>Mystic</td>
<td>0.5650</td>
<td>0.0013</td>
<td>99.77</td>
<td>240</td>
<td>540</td>
</tr>
<tr>
<td>4º</td>
<td>Refugy</td>
<td>0.4669</td>
<td>0.0078</td>
<td>98.33</td>
<td>240</td>
<td>50</td>
</tr>
<tr>
<td>5º</td>
<td>Safari</td>
<td>0.3394</td>
<td>0.0057</td>
<td>98.32</td>
<td>240</td>
<td>50</td>
</tr>
</tbody>
</table>

The obtained values allow continuous reuse in the 5-colour dyeings and also in the all-white dyeings.

#### 3.1.1. *Reuse of effluent: White dyeings.* The Wi values were used as comparisons between white dyeings executed with treated effluent versus white dyeings executed with water, as described in Table 4.

<table>
<thead>
<tr>
<th>White dyeing executed after treatment of effluent:</th>
<th>Water</th>
<th>Treated effluent</th>
<th>$\Delta$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Black</td>
<td>152</td>
<td>152</td>
<td>0.00</td>
</tr>
<tr>
<td>2-Cosmic</td>
<td>149</td>
<td>148</td>
<td>0.67</td>
</tr>
<tr>
<td>3-Mystic</td>
<td>155</td>
<td>148</td>
<td>4.52</td>
</tr>
<tr>
<td>4-Refugy</td>
<td>146</td>
<td>144</td>
<td>1.37</td>
</tr>
<tr>
<td>5-Safari</td>
<td>145</td>
<td>139</td>
<td>4.14</td>
</tr>
</tbody>
</table>

**Deviation Media** 2.14

For the results presented, in which the average deviation was lower than 3%, it is concluded that the difference was not significant between the white dyeings executed with normal water and the treated effluent, which demonstrated that the process can be applied not only for future dyeings of colours but also for washes and other bleaching processes.

#### 3.1.2. *Reuse of effluent: Colours.* The $\Delta$E* values that were used as comparisons between colours dyeings executed with treated effluent versus colours dyeings executed with water are described in Table 5.

<table>
<thead>
<tr>
<th>Color</th>
<th>$\Delta a^*$</th>
<th>$\Delta b^*$</th>
<th>$\Delta L^*$</th>
<th>$\Delta a^*$</th>
<th>$\Delta b^*$</th>
<th>$\Delta L^*$</th>
<th>$\Delta E^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>23.81</td>
<td>-2.14</td>
<td>-12.04</td>
<td>24.21</td>
<td>-2.29</td>
<td>-12.17</td>
<td>0.45</td>
</tr>
<tr>
<td>Cosmic</td>
<td>30.75</td>
<td>6.35</td>
<td>-10.72</td>
<td>30.68</td>
<td>6.31</td>
<td>-10.82</td>
<td>0.13</td>
</tr>
<tr>
<td>Mystic</td>
<td>36.83</td>
<td>15.94</td>
<td>1.06</td>
<td>37.95</td>
<td>15.81</td>
<td>1.09</td>
<td>1.13</td>
</tr>
<tr>
<td>Refugy</td>
<td>32.82</td>
<td>2.53</td>
<td>3.36</td>
<td>32.09</td>
<td>3.20</td>
<td>3.36</td>
<td>0.99</td>
</tr>
<tr>
<td>Safari</td>
<td>49.07</td>
<td>14.34</td>
<td>18.96</td>
<td>48.19</td>
<td>15.00</td>
<td>18.95</td>
<td>1.10</td>
</tr>
</tbody>
</table>
The presented $\Delta E^*$ values for all developed colours are below 1.5, which are accepted values in the Brazilian market.

3.1.3. Colourfastness. The values of the colourfastness test are described in Table 6.

<table>
<thead>
<tr>
<th>Color</th>
<th>Water</th>
<th>Treated effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>S</td>
</tr>
<tr>
<td>Black</td>
<td>4</td>
<td>3/4</td>
</tr>
<tr>
<td>Cosmic</td>
<td>4</td>
<td>3/4</td>
</tr>
<tr>
<td>Mystic</td>
<td>4/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Refugy</td>
<td>4/5</td>
<td>4/5</td>
</tr>
<tr>
<td>Safari</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

*Obs: C = Color change; S = Staining*

The difference between the colours executed with water and the colours executed with the treated effluent is not significant. The difference between the values was not higher than ½ point.

3.1.4. TOC. Table 7 shows the values obtained after 5 dyeings with water and with treated effluents.

<table>
<thead>
<tr>
<th>Total Organic Carbon</th>
<th>mg L$^{-1}$</th>
<th>% Remotion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed process (*)</td>
<td>34</td>
<td>92.89</td>
</tr>
<tr>
<td>Conventional process (**)</td>
<td>435</td>
<td></td>
</tr>
</tbody>
</table>

(* = after last treatment; (**) = effluent of 5 dyeings)

The amount of TOC after treatment with the 5th dyeing was 34 mg L$^{-1}$ compared with 435 g L$^{-1}$ presented after 5 dyeings that were executed with no treatment. The treatment promoted 93% of TOC reduction.

3.1.5. Salinity. The amount of NaCl present after the last treatment was 2.34 g L$^{-1}$ compared with 25.0 g L$^{-1}$ after fifteen dyeings executed by the conventional process, which is a decrease of approximately 95%. This difference is due mainly to the amount that is already present in the treated effluent for implementing the following dyeing, which was subtracted from the amount of NaCl recommended by the supplier of the original recipe.

3.1.6. Toxicity. The EC$_{50}$ presented values, with 95% confidence interval, were 10.15 for the effluent after 5 dyeing against <6.25 for the treated effluent. The effluent treated cause 100% mortality of the microorganisms, which means that the treated effluent sample was more toxic than the effluent after five dyeings done by conventional methods.

4. Conclusion

Based on the results in this study, which present 5 colours achieved with the studied dyestuffs, we found that the proposed treatment and process can be applied for the purpose of reusing the treated effluent not only in the new colours dyeings but also in other process such as bleaching, washing off and white dyeings. However, the treated effluent presented more toxicity, increasing the mortality to *D. Similis*. The results suggest an evaluation with more than one class of test organism.

The colourfastness of the dyeings achieved with treated effluents did not present a significant difference compared with the dyeings achieved with water. The difference between the $\Delta E^*$ values in the studied colours were lower than 1.5 points. Moreover, the white dyeings achieved with treated effluent showed Wi values similar to white dyeings made with water. The median of the deviations did not exceed 3%. In some cases, white dyeings achieved with treated effluent showed a higher Wi value than the white dyeings achieved with water.
The average water consumption for dyeing a kilogram of cotton was 24 L after fifteen dyeings achieved by the proposed process using the colours and dyestuffs studied, which is less compared with the 70 L that were consumed by the same dyeings achieved by the conventional process. Theoretically, in the dyeing of 1000 kg executed by the proposed process leads to eventual replenishment of water about 10%, indicate that the economy would conserve approximately 66.5 m$^3$ of water when compared to conventional process.

Acknowledgement

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5. References

Physical properties of recycled PET non-woven fabrics for buildings

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Abstract: Recycled fibers have been commonly used in non-woven production technology for engineering applications such as textile engineering and civil engineering. Nonwovens including recycled fibers can be utilized in insulation, roofing and floor separation applications. In this study, physical performance properties such as drape, bending resistance, tensile strength, and breaking elongation values of non-woven fabrics consisting of v-PET (virgin) and r-PET (recycled) fibers in five different blend ratios are examined comparatively. The test results indicated that r-PET can be used in non-wovens for civil engineering applications such as insulation, roofing and floor separation fulfilling the acceptable quality level values.

1. Introduction
In recent years, recycling has been an attractive issue for researchers considering sustainability of the wastes arising from different engineering applications. In this scope, r-PET fibers which are mechanically and chemically recycled from PET bottles can be reused in needle punched non-woven production technology in profitable amounts. The first PET bottle recycling process made by the company, known as Jude Polymers, in 1976, by converting PET bottles into plastic belts and paint brushes [1]. It is known that 72% of the recycled PET flakes are used for fiber production [2]. In order to recycle PET and to be particularly suitable for secondary use, it is necessary to carry some physical properties. Otherwise, it is impossible for secondary usage. Some physical properties of recycled PET should have are listed in Table 1. Besides some researches indicated that 1 kg of PET sawdust from 1.246 kg of PET bottles by mechanical recycling and 1 kg of PET polymer of 1.133 kg of PET bottles by chemical recycling can be obtained [3].

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>[n]</td>
<td>&gt;0.7 dl g⁻¹</td>
</tr>
<tr>
<td>Tm</td>
<td>&gt;240 °C</td>
</tr>
<tr>
<td>Water Content</td>
<td>&lt;0.02 wt %</td>
</tr>
<tr>
<td>Flake Size</td>
<td>0.4&lt;D&lt;8 mm</td>
</tr>
<tr>
<td>Dyestuff content</td>
<td>&lt;10ppm</td>
</tr>
<tr>
<td>Yellowing Index</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Metal Content</td>
<td>&lt;3ppm</td>
</tr>
<tr>
<td>PVC Content</td>
<td>&lt;50ppm</td>
</tr>
<tr>
<td>Polyolefin Content</td>
<td>&lt;10ppm</td>
</tr>
</tbody>
</table>

Table 1 Properties of Recycled PET should carry [1].
Considering some application areas of r-PET, it is observed that fiber, yarn and fabric forms can be used respectively. Especially, morphological structures, common characteristics and differences in physical and chemical properties by changing production parameters of r-PET and v-PET fibers were investigated [4-5]. Many researchers have studied at different recycling methods, different spinning speeds and blend ratios of r-PET yarns to investigate their physical properties [6-8]. r-PET has been widely preferred to be used in denim fabrics, knitted fabrics and non-woven textile materials for its easy availability[9-11]. Other's works and scientific reports have proved that plastic wastes and especially recycled PET may be applied for modifications of road pavement asphalt and also building concretes in construction industry [12-13]. The weight of a fabric covered with same area is about 1/30 of that of brick, steel or concrete. In this way, it has provided both less costs and less amount of reinforcement [14].

In this study non-woven fabrics made of v-PET (virgin) and r-PET (recycled) fibers in five different blend ratios are produced through a conventional needle punching system. Physical performance properties of these fabrics are examined by means of drapability, bending resistance, tensile strength, and breaking elongation tests. The test results are statistically evaluated in the SPSS programme.

2. Materials and methods

2.1. Materials
In the study, v-PET (virgin) and r-PET (recycled) fibers are used as raw materials for the non-woven fabric production. Before production, the length, fineness, and cross-sectional appearance of the fibers were examined. It is observed that the number of crimp of v-PET fibers, texturized, is twice the number of crimp r-PET which is not texturized and tensile strength of the r-PET fibers are approximately two times higher than those of v-PET. Structural properties of r-PET and v-PET fibers are presented in Table 2.

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Crimp (1/cm)</th>
<th>Fiber Strength (cN/dtex)</th>
<th>CV Strength (%)</th>
<th>Breaking Extension (%)</th>
<th>CV Breaking Extension (%)</th>
<th>Fiber Fineness (dtex)</th>
<th>Fiber length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>v-PET</td>
<td>4.2</td>
<td>3.39</td>
<td>17.9</td>
<td>31.07</td>
<td>19.1</td>
<td>3</td>
<td>60</td>
</tr>
<tr>
<td>r-PET</td>
<td>2.2</td>
<td>5.06</td>
<td>14.4</td>
<td>44.75</td>
<td>25.22</td>
<td>3</td>
<td>60</td>
</tr>
</tbody>
</table>

2.2. Methods
In needlepunching process fibers are entangled through barbed needles during the strokes of needle loom. Five different blends of the afore-mentioned fibers have formed as follows: 100 % v-PET; 70% v-PET and 30 % r-PET; 50% v-PET and 50 % r-PET; 30 % v-PET and 70 % r-PET; and 100 % r-PET. Since blends consist of synthetic fibers, they are laid to rest for 24 hours after antistatic materials are applied to prevent electrification. Then non-woven fabrics using these blends have been produced in 6, 10, and 14 layers.

During production, fiber feeding direction, production speed, needle orientation and type are kept stable. Preliminary needling is carried out with 10 mm needling depth using 4000 needles at 150 rpm and the main needling is carried out with 3 mm needling depth using 40000 needles at 450 rpm. The speed of production is kept constant at 42 m/h.

Datum obtained from the different blends with same weights and same blend with different weights are examined. All fabric samples are conditioned at 20 ± 2 °C and 65 ± 2% relative humidity before they are subjected to the specified tests for at least 24 hours. The fabric thickness is determined
Based on TS 7128 EN ISO 5084 standard. The determination of the tensile strength is based on TS EN ISO 13934-1, "Stretching Properties of Textile-Fabrics-Part 1: The Strength of the Biggest Strength and the Strongest Strength under the Greatest Strength-Strip Method" standard. The determination of bending resistance and fabric weight are based on TS EN ISO 9073-7 "Determination of Bending Strength of Woven Textile Products" standard and "Determination of Unit Length and Unit Area Mass ISO 3801 Method 5 TS 251", respectively [15-18].

3. Results
Thickness, weight, drape, bending resistance and tensile strength tests have been carried out to evaluate the physical performances of these 15 fabrics. The mean values of results are demonstrated in Table 3. The effects of blending ratio on drape, bending resistance, tensile strength, and breaking elongation between groups according to the analysis of variance at 95% confidence level (p < 0.05) are listed in Table 3. The comparisons and differences among the groups for fabric type are performed using post-hoc Tukey and Games-Howell tests depending on homogeneity of variances. “a”, “b”, “c” and “d” letters are used in Table 3 to indicate the differences of measured average values of all type of fabrics.

Table 3 The mean value of results.

<table>
<thead>
<tr>
<th>Fabrics</th>
<th>Drape(%)</th>
<th>Rigidity (mm) (MD)</th>
<th>Rigidity (mm) (CD)</th>
<th>Tensile Strength (N) (MD)</th>
<th>Tensile Strength (N) (CD)</th>
<th>Breaking Elongation (mm) (MD)</th>
<th>Breaking Elongation (mm) (CD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% r-PET</td>
<td>92.94</td>
<td>257.52</td>
<td>289.88</td>
<td>70.14</td>
<td>142.69</td>
<td>16.04</td>
<td>27.05</td>
</tr>
<tr>
<td>70% r-PET 30% v-PET</td>
<td>89.48</td>
<td>77.57</td>
<td>136.71</td>
<td>42.77</td>
<td>57.78</td>
<td>16.43</td>
<td>28.53</td>
</tr>
<tr>
<td>50% r-PET 50% v-PET</td>
<td>91.96</td>
<td>81.16</td>
<td>162.56</td>
<td>25.15</td>
<td>39.35</td>
<td>13.77</td>
<td>26.26</td>
</tr>
<tr>
<td>30% r-RET 70% v-PET</td>
<td>88.68</td>
<td>80.23</td>
<td>123.25</td>
<td>29.03</td>
<td>35.13</td>
<td>14.92</td>
<td>28.15</td>
</tr>
<tr>
<td>100% v-PET</td>
<td>9580</td>
<td>165.87</td>
<td>268.44</td>
<td>27.11</td>
<td>46.10</td>
<td>15.16</td>
<td>27.35</td>
</tr>
</tbody>
</table>

| 20 layer                 |          |                    |                    |                            |                            |                               |                               |
| 100% r-PET               | 97.59    | 919.99             | 1439.12            | 177.99                     | 448.54                     | 11.77                         | 21.64                         |
| 70% r-PET 30% v-PET      | 96.20    | 542.60             | 1354.66            | 142.22                     | 339.15                     | 12.88                         | 24.37                         |
| 50% r-PET 50% v-PET      | 96.55    | 526.82             | 876.33             | 120.85                     | 248.34                     | 12.25                         | 26.28                         |
| 30% r-RET 70% v-PET      | 95.92    | 433.19             | 433.19             | 108.41                     | 221.95                     | 12.68                         | 25.53                         |
| 100% v-PET               | 97.43    | 1206.12            | 1430.15            | 146.73                     | 363.49                     | 13.56                         | 24.24                         |

| 34 layer                 |          |                    |                    |                            |                            |                               |                               |
| 100% r-PET               | 98.76    | 5162.70            | 4513.70            | 495.96                     | 967.25                     | 12.04                         | 16.23                         |
| 70% r-PET 30% v-PET      | 96.19    | 2170.93            | 5246.32            | 397.45                     | 803.17                     | 11.55                         | 17.67                         |
| 50% r-PET 50% v-PET      | 97.85    | 1838.87            | 4158.49            | 301.70                     | 514.95                     | 12.05                         | 18.59                         |
| 30% r-RET 70% v-PET      | 97.75    | 2420.06            | 4357.54            | 247.00                     | 465.52                     | 11.18                         | 20.71                         |
| 100% v-PET               | 97.86    | 9464.04            | 5797.81            | 296.91                     | 380.77                     | 13.77                         | 21.14                         |

Note: The average values are arranged such that the letter 'a' shows the lowest average value and the letter 'c' shows the highest average value. Any two average values not sharing a letter in common mean that they are significantly different from each other at 95% confidence level.

3.1 Weight and thickness
Increasing production layer from 6 to 14 under constant production circumstances has raised reasonably weight and thickness values of fabrics. Measured thickness and weight values and expected weight values of blended fabrics according to %100 fabrics showed in Table 4. Thickness and weight values of 100% v-PET and 100% r-PET fabrics are found to be fairly close. Considering the blended fabrics in three different ratios; thickness and weight values are measured as compatible with each other. However, measured weight values of blended fabrics are found to be much lower than expected weight values. It is considered that the difference between measured and expected weight values become husks. The percentage of husks changes between %19.81 and %31.86 and increases with the higher percentage of r-PET amount. This is because of in capability of the stiff and non-texturized r-
PET fibers to entangle and to locate in the structure. Losses of fibers affect the thickness values in the same manner.

**Table 4** Weight and thickness value of results.

<table>
<thead>
<tr>
<th>Fabrics</th>
<th>Weight (g/m²)</th>
<th>Expected</th>
<th>Weight (g/m²)</th>
<th>Observed</th>
<th>Husk (%)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% r-PET</td>
<td>165.08</td>
<td></td>
<td>165.08</td>
<td>-</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>70% r-PET 30% v-PET</td>
<td>156.48</td>
<td>112.43</td>
<td>28.15</td>
<td>0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% r-PET 50% v-PET</td>
<td>150.74</td>
<td>117.63</td>
<td>21.96</td>
<td>0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30% r-RET 70% v-PET</td>
<td>145.00</td>
<td>116.28</td>
<td>19.81</td>
<td>0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% v-PET</td>
<td>136.40</td>
<td></td>
<td>136.40</td>
<td>-</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>70% r-PET 30% v-PET</td>
<td>308.83</td>
<td>308.83</td>
<td>-</td>
<td>1.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% r-PET 50% v-PET</td>
<td>308.25</td>
<td>244.85</td>
<td>20.57</td>
<td>0.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30% r-RET 70% v-PET</td>
<td>307.87</td>
<td>243.90</td>
<td>20.78</td>
<td>0.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% v-PET</td>
<td>307.48</td>
<td></td>
<td>306.90</td>
<td>-</td>
<td>1.65</td>
<td></td>
</tr>
<tr>
<td>10 layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% r-PET</td>
<td>540.10</td>
<td></td>
<td>540.10</td>
<td>-</td>
<td>2.85</td>
<td></td>
</tr>
<tr>
<td>70% r-PET 30% v-PET</td>
<td>568.79</td>
<td>395.65</td>
<td>30.44</td>
<td>1.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% r-PET 50% v-PET</td>
<td>587.92</td>
<td>400.63</td>
<td>31.86</td>
<td>1.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30% r-RET 70% v-PET</td>
<td>607.04</td>
<td>477.80</td>
<td>21.29</td>
<td>2.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% v-PET</td>
<td>635.73</td>
<td></td>
<td>635.73</td>
<td>-</td>
<td>2.82</td>
<td></td>
</tr>
</tbody>
</table>

3.2 Drape
The increase in the number of layers has negative effect on the drape properties of all fabrics. The effects of blending ration on the drape properties of all fabrics are statistically insignificant as shown in Figure 1 and Table 3.

![Figure 1](image)

**Figure 1** Drape values of production groups.

3.3 Bending rigidity
Bending rigidity values of the fabrics in both machine direction and cross machine direction have been measured. The rising number of layers has reduced the bending ability of fabrics in both directions because of increase in weight and thickness values. The effects of blending ratio on the bending rigidity of fabrics in both directions are statistically insignificant as shown in Figure 2 and Table 3. The bending ability of all 100% fabrics are not crucially different. The bending rigidity of CD-fabrics of all layers are higher than that of MD-fabrics. This is probably because of cross layout of web.
3.4 Tensile strength and breaking elongation

Tensile strength of samples is tested in both machine direction and cross machine direction and results shown in Figure 3. The increase in the number of layers has positive effect on the tensile strength and negative effect on breaking elongation of all fabrics as shown in Table 3. The tensile strength of CD-fabrics of all layers are higher than that of MD-fabrics. This is probably because of cross layout of web and higher fiber orientation in cross machine direction. Conversely, the breaking elongations of CD-fabrics of all layers are lower than that of MD-fabrics. The tensile strength of 100% r-PET fabrics is higher than that of 100% v-PET fabrics because of higher fibers strength of r-PET. The breaking elongation all 100% fabrics are not different statistically. Although the effects of blending ratio on the tensile strength and breaking elongation of fabrics in both directions are statistically insignificant, higher r-PET ratio causes higher tensile strength and lower breaking elongation. Since, increasing the r-PET ratio added into blend leads to increment in husks amount thus, the effect of r-PET ratio on tensile properties is disguised.

4. Conclusions

The non-woven fabrics with 5 different blends of r-PET and v-PET fibers in 6, 10, and 14 layers have been produced. Weights, thickness, drape, bending resistance, tensile strength, and breaking elongation properties have been evaluated. As expected, ticker and heavier fabrics have less drape ability and breaking elongation while more bending rigidity and tensile strength. The effect of blending ratio on fabric properties can be seen more clearly if the amount of r-PET is increase by
about 24% in order to reduce husks. r-PET non-woven fabrics are competitive with v-PET non-woven fabrics in many ways for construction industry where tensile and shape ability properties are necessary.

**Acknowledgements**

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Fashion design solutions for environmentally conscious consumers

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Abstract. This paper intends to give an overview of the design solutions in fashion for environmentally conscious consumers, presenting green and ethical practices in contemporary clothing design. The results introduce the concept of slow fashion and discuss available fashion design solutions, giving most prominent examples of sustainable products and brands, these contain one or more design features. By this, the discussion extracts the main contemporary ideas. The presented examples of current offers are all envisioning less impact on the environment and society. Sustainable design solutions use more environmentally friendly materials such as organic cotton, incorporate circular design or design for recycling, e.g., replacing button closures with alternative closing possibilities or leather labels with printed versions, or ensure long product life through durability, among other methods. There are differing designs due to creators’ individuality. This overview can be beneficial for the future development of new solutions for more environmentally friendly fashion.

1. Introduction
The present study is part of a PhD project in sustainable design and management of textiles, focusing on consumer perception of ethical fashion. To understand consumer perception, the concept of ethical fashion is analysed in here, identifying design solutions existing in clothing nowadays. The contemporary clothing design can show changes in society.

Ethical or sustainable fashion might sound like a paradox. The fashion industry is one of the most polluting industries and consumers, and their consumption patterns are one of the challengers. But, sustainability, in general, is rising and affecting all kind of business, also textiles: Sustainability has become a key issue in the fashion industry over the past year [1]. The promotion of ethical fashion is becoming more prominent in the fashion industry, also seen in the example of the Ethical Fashion Show in Germany, held parallel to the Berlin Fashion Week; In their Green Showroom, brands from the street and casual wear are present with the focus on design and sustainability: urban Zeitgeist, eco-fair lifestyle and fashion [2]. Eco fashion is focusing more and more on the design, reducing the perception of old-fashioned eco clothing. Contemporary eco clothing design needs to be able to balance ethics, aesthetics and functionality.

According to the push and pull marketing concepts, not only the industry but also consumers are influencers, creating new challenges through their impact on the environment. Consumers have
become more demanding and aware of environmental issues [3]. The question arises, how these consumer needs for more environmentally friendly fashion solutions influence the design of garments?

In differently reported studies, consumer behaviour analysis focuses on consumer motivations and decision-making. In this context, ethics reflects morals and leads to pro-social behaviour; Researchers noticed that consumers tend to give socially desirable answers to questions related to their sustainable behaviour, resulting in an attitude-behaviour gap [4–6]. Instead, the study can focus on the measurement of the attitude towards the product design and attributes to define ethical consumer behaviour. Clothing designers are incorporating sustainability into their design strategies and material choices as discussed in the following, presenting contemporary consumer products found in sustainable fashion.

2. Approach
This study investigates into the slow fashion concept and the contemporary design solutions available, and aspects related to environmentally conscious consumers are discussed, presenting most prominent examples of sustainable products, emphasizing on one or more design possibilities, having a better environmental performance than traditional solutions. Results for sustainable practices are presented according to the six main solutions defined by Caniato et al. [7], see table 1, and based on the experience found in literature and current trends, as well as including consumer needs.

<table>
<thead>
<tr>
<th>Table 1. Main sustainable solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainable solutions</td>
</tr>
<tr>
<td>(i) use of organic fibres</td>
</tr>
<tr>
<td>(ii) reuse and recycling of materials</td>
</tr>
<tr>
<td>(iii) vintage practices and second-hand</td>
</tr>
<tr>
<td>(iv) clean technologies</td>
</tr>
<tr>
<td>(v) green certifications</td>
</tr>
<tr>
<td>(vi) green product and process design</td>
</tr>
</tbody>
</table>

3. Results and discussion
The presented examples of current trends and offers grouped according to the sustainable solution categories have all in common that they have less impact on the environment or society. Referring to the first category, sustainable design solutions use more environmentally friendly materials such as organic cotton. Secondly, by incorporating circular design or design for recycling, designs can replace button closures with alternative closing possibilities or leather labels with printed versions, or among other methods, ensure long product life through durability. There is a broad variety, design solutions are different due to designer individuality and the influence of other factors, such as social and fashion trends. Designs are shaped by various factors such as branding as well as consumer needs, resulting in the design solutions presented in this study. To promote sustainable fashion, consumer needs have to be defined and met accordingly through offering the right design solutions that should have physical but also emotional durability such as long lasting wear and relevance or desirability of consumers.

3.1 Slow fashion concept
On the one hand, due to the environmental problems in the fashion industry and on the other hand, due to the consumer demand and more consciousness, a new concept rises along the traditional fast fashion concept. The slow fashion concept refers to the slow food movement, which focuses on local and small producer [8]. According to the Slow Fashion Award [9], the concept describes high quality realised through design, as well as fair labour conditions. The general aim is to reduce the negative environmental impact of fashion and its processes. This is caused by the use of chemical products, the
exploitation of finite resources, and the high CO₂ emissions [10]. In the following, examples of changes from the fast to the slow fashion design are discussed, inspired by environmental and ethical issues occurring in the fashion industry.

3.2. Sustainable fashion design practices
To create eco or environmentally friendly fashion, sustainable practisers are operating on several levels, either in the whole supply chain or solely in a single company [11]. Eco design can also focus, besides the steps involved in the supply chain, on the pre-consumer phase which includes production and transportation, and it can apply in the use or the post-consumer phase, either through recycling or upcycling. For clothing it has been seen that the environmental impact can be strongly influenced by the use phase of the consumer in the care phase or laundering; additionally, it is possible to involve all the stages of the lifecycle, including at the systems design level [12].

3.2.1. Organic fibres. Organic fibres have less impact on the soil or environment due to the lack of use of toxic insecticides, herbicides or fungicides [7]. Most prominent example for the use of organic fibres in clothing is organic cotton. Often, consumers tend to prefer natural fibres to synthetic [13]; however, most consumers are not aware of the real impact in the production process. E.g., to produce one kilogram of cotton, a high amount of water is needed, up to 10,000 litres of water.

Other natural raw materials from a plant are hemp or kapok, and from an animal source wool and silk which are available as organic wool and peace silk, this refers to a more ethical procedure of gaining the fibres. The wool process is mulesing free, and the alternative silk process can gain the silk without boiling and killing the silk worm. Still, for consumers being highly ethical and therefore avoiding animal products, i.e., living a vegan lifestyle, wool and silk are not suitable.

An example is that of the US brand Patagonia with a management based on sustainable development and an offer of innovative and efficient products [14]. The design strategy uses only organic cotton, and focuses on both the product quality and sustainability [10]. Also, consumers show importance of the origin of the raw material; The Ethnicity report [15] states the high interest of French consumers towards the origin of raw materials and production location compared to environmental or social impact in general in production process [16]: Local suppliers are shortening the transportation cycle. Also, another fibre approach focuses on using more durable textile materials which can prolong the product life, or more sustainable materials such as recycled fibres, described in the following.

3.2.2. Reuse and recycling. The reuse and recycling of materials have a lower impact on the environment by saving resources and decreasing landfill. The three concepts are the three R’s, to reduce, reuse and recycle. The traditional concept of a linear process is transformed into a circular one, incorporating circular design. When designing for recycling, additional considerations have to be made, such as material content and product accessories; i.e., there are difficulties in recycling products according to a separation of different materials and accessories such as buttons or labels. Therefore, the design process can already focus on design for circularity by, e.g., replacing button closures with alternative closing designs or leather labels with printed versions.

Besides old clothing from e.g. manufacturing scraps, also other materials can be used in the fashion design such as bottles and tyres [7]. Most prominent example is the recycling of truck canvas by the Swiss company FREITAG, selling backpacks, bags and other accessories made from recycled material such as old truck canvas, safety belts or bicycle tubes [17]. Using this concept, the brand offers unique designs and creates a lifestyle product with more value. Other companies worldwide are adopting similar concepts. Examples are the Romanian brand upside-down, selling products Made in Romania and reusing materials such as from old outdoor advertising banners and billboards [18]. Or, another example is the Turkish brand %100 ISTANBUL, which sells upcycled bags in their concept store made from recycled seed or food sacks and also exhibition banners and others [19].

Another prominent example is the German sports brand Adidas and the launch of Parley for the Oceans, using recycled ocean plastic for their products [20]. Besides sneakers, also swimwear
products are offered, made from upcycled fishing nets and debris; the design of the products is inspired by the sea, using blue colours and the wave structures among others. On the one hand, especially when it comes to performing products, the quality has to be ensured. Recycled products have been seen to cause the problem of trust in quality. In the luxury sector, research revealed that the consumer perception of the products made from recycled materials is negative [21].

3.2.3. Vintage and second-hand. These practices are offering a unique fashion to consumers. Consumers can have nostalgic emotions towards them and require different styles than these available on the current market. Moreover, due to cost reasons, the second-hand options are desirable, especially for price-conscious consumers or those with lower incomes, such as students. For specific types of clothing such as children wear, second-hand clothing is preferred as children grow fast and require bigger sized garments. Other alternative models or approaches offer clothing that customers can rent, share, lease, or switch.

3.2.4. Clean technologies. Besides information technologies [22], companies focus on the improvement of product processes, e.g., using less water during dying or using natural dyes, i.e., vegetable and plant dyes. Also, social cause care is included, by basing dying on traditional methods. In this context, companies are working with a non-profit organisation to develop sustainable community-based projects.

3.2.5. Green certifications. Besides the traditional design requirements, the design for green products follows certain eco standards. As mentioned before, organic cotton is well known; Besides, certifications include the fair trade of suppliers. A prominent example of certification is the GOTS (Global Organic Textile Standards) and the Fairtrade certification or Fair Wear Foundation. Also, there are country-specific certificates, such as the Bündnis für Nachhaltige Textilien from Germany; others are the Öko-Tex. The certifications need certain measurements accordingly, such as through the LCA (life cycle assessment).

3.2.6. Green product and process design. A green product can present one of the six in here mentioned solutions, or several or all of them. Referring to the example of organic cotton, using a single approach this means that the textile material is certified as coming from a fair trade source; but to include multiple approaches, other factors should be considered as well. These considerations include for example the dyeing, i.e., using natural dye to avoid chemical substances. Hereby the whole product becomes sustainable. Besides the product, sustainable design also applies to the packaging and services, using improved packaging and giving consumer advice on garment care such as washing with lower temperature and less often, or offering disposing services to customers, e.g., H&M and their Garment Collecting service [23]. Therefore, besides the product characteristics and the materials used, also production technologies and services should be included to define a green product to be sustainable [7]. As mentioned, consumers and their use phase have an influence on the products’ sustainability, see the following.

3.3 Sustainable fashion consumers’ needs

Consumers can be the main influencers in the design process of products, refer to the concept of consumer-centred design. Also, through their ‘përster’ power, especially in social media or through feedback systems, their opinion becomes important and can influence either positively or negatively. Environmental consumers have been seen to passively or actively promote or boycott products related to environmental issues or ethics, such as boycotting brands and products using fur or angora wool.

Therefore, the perception and decision-making process of consumers is a rising topic in research and company’s marketing departments. The research on consumer behaviour, and especially on ethics, needs a sensitive approach, due to bias in what the consumers state and how they behave; refer to the previously mentioned attitude-behaviour gap due to socially desirable answers.
Different researchers tried to define the factors that can minimise this gap. One approach is to focus not only on ethics in the product - it has been found that ethicality might not be the main purchase criteria - but also on other factors such as price and availability [24, 25]. Also, as there is a broad variety of key influence factors and buying motivations, and the function the fashion item performs varies strongly [26], two categories in product design were defined; the functional and symbolic product attributes [27], whereby the product can also own both. Concluding, besides general product features and sustainable design, emotions have to be included into the design to achieve full consumer satisfaction.

4. Conclusions
The results show that contemporary fashion design offers several solutions for the environmentally conscious consumer. However, there is a necessity for more information on both sides, for the consumer and the company related stakeholders to create real sustainable products. Evaluation tools such as LCA are helpful to determine the real value; marketing tools are necessary to promote the sustainable value towards the consumer, including traditional factors as well as contemporary evaluators such as sensory features like emotions and feeling. The presentation of the right information about the product is crucial to promote the green product; different types from several sources are available. Researchers need to consider subjective attributes and analyse according to the brand values if the product incorporates this image. This overview can benefit the future development of new solutions in sustainable clothing design, in further research the acceptance of the various concepts needs testing.

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