CHALLENGES AND SOLUTIONS FOR RECOVERING MIXED FIBER WASTE FROM KNITTED USED TEXTILES

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Data Availability Statement: All relevant data are within the paper and its Supporting Information files.
Competing Interests: The Author(s) declare(s) no conflict of interest
10.36253/fh-2979

Abstract

Pure new wool is rarely found as a quality in German used clothing sorting plants. On the other hand, large quantities of synthetic fiber-wool blends are produced as a waste product of the fast fashion industry. The multiple blends in particular lead to a high loss of value. Previous studies have shown that fiber blends with up to seven different fibers are in circulation within one piece of clothing. Better qualities find their second use in second-hand stores, while lower qualities are categorized and sorted in sorting plants according to their material composition and have so far mostly been processed as filling and insulating materials.
In order to recycle these fibers for the clothing sector, two areas of mechanical recycling are being analyzed and modified within my PhD research.
The finer sorting, as well as the subsequent cutting and tearing process, have a significant influence on the fiber dissolution of the textile surface, as well as on a process-stable yarn production.
Varying fiber blends from used clothing need to be prepared in a process-stable manner so that they can be used as standard raw materials in the future.

Keywords: *Post Consumer Waste, Recyclability, Mechanical Recycling, Process Optimization, Shredded Fibres*

INTRODUCTION

Do we know our currently available resources in the field of fibre recycling?
We usually know the mixing ratios of pre-consumer waste, as waste from production, because it is about virgin fibres and yarns, where the fibre mixtures are known. However, the knowledge gap arises mainly with the mostly unknown material blends of our post-consumer waste, as we not know how it can be re-spun into new yarn and which renewed blend ratios are suitable for this.
Our current knowledge of fibres relates in particular to the sustainable aspects of our available virgin fibres, from cotton, wool, synthetic fibres and the impact of fast fashion. We know that all fibres, no matter how sustainably they are marketed, have their drawbacks in terms of the environment or animal welfare due to the requiered quantity. Therefore, it would be most sustainable not to produce anything from virgin fibres or at least to reprocess the previously used fibres from the pre- & post-consumer waste and to use them as an available resource of equal value in order to reduce the consumption of virgin fibres.
Robin Wall Kimmerer wrote in her book, Braiding sweetgrass:”We have a choice. If the whole world is a commodity - what poverty. If the whole world is a circulating gift - what wealth.”(Kimmerer, 2021)
As an environmental biologist with an indigenous background, she is very much concerned with the holistic consideration of nature and the human being, an aspect I find entirely neglected in the

context of the textile chain and the active awareness of fast fashion. The holistic view of the textile chain and the resources available to us as designers in terms of fibres is an essential point of my research. To address this problem, the most logical decision would be to stop producing new items. The growing second-hand market and the slow fashion movement offer approaches to counteracting the problem. With my background in fashion design, however, my goal is to develop solutions on an industrial scale that enable designers to continue creating new items, but that incorporate processes across the entire textile chain. In my PhD research, titled Re: value-Holistic consideration of the wool fibre cycle for clothing textiles, in particular the recovery of mixed fibre waste from knitted post consumer waste, I focus on the recovery of mixed-fibre waste from post-consumer knitted textiles. This involves developing a recycling process that addresses the problems of fast fashion waste and uses the design process to transform discarded materials into higher-value clothing. The design process must be rethought in the future by integrating the entire textile chain and adopting a Design for Recycling perspective, in order to ultimately recognize clothing as a valuable, preferably circulating commodity, rather than designing for linear consumption.
This includes to actively integrate recycled fibres in the design process, cancel toxic dying processes, design more in similar color ranges and use the huge field of complex knitting & weaving bindings for our designs. The focus in the design should be increasingly on the longevity and future recycling potential of the product.
If we talk about recycled fibres, this leads to the essential question: How recyclable is our current clothing and: What influence does the admixture of synthetic fibres have on future recyclability, especially to wool fibres from our current available post-consumer waste generated by fast fashion? Textile engineers as well as textile and fashion designers are based on a multitude of natural and synthetic fibres that can be mixed in almost unlimited combinations and mixing ratios for further processing in the textile chain, leading to an even greater variety of garments. On the one hand, this playing field opens up a great many possibilities due to the constantly changing fashion trends and our everyday sensitivities, but it also leads to very complex mixing ratios between natural fibres and cellulose-based and/or petroleum-based synthetic fibres that are currently hardly recyclable in terms of their recyclability. In this respect, it is important to find out to what extent we as textile engineers as well as textile and fashion designers need to rethink together at the beginning of the textile chain in order to be able to better guarantee the recyclability of our worn clothing in the future.
My research approach is based on intensive research in the field of wool mixed fibers, a part of recycling that currently receives little attention. The reasons for this are the excessively expensive labor costs for a currently manual sorting process and the different compositions of the wool blends, which differ greatly in their physical textile properties. It is difficult to derive consistent parameters for yarn production. The shredded wool produced from the wool blend fibers, which is currently used for insulation materials and thus downcycled, must be researched in order to use the fibers within the clothing industry cycle and transfer them to recycling. The raw material for the research-related experiments is obtained from locally available resources. The term downcycling refers to products whose quality is inferior to the original material. A classic example is the production of shredded fibers from old clothes, which are used as insulating material in the construction and automotive industries. The term recycling, on the other hand, includes products of equivalent quality, such as fiber-to-fiber recycling, where the yarn produced can be used again for the production of textile surfaces. The term upcycling includes products whose quality is higher than that of the original material due to a material upgrade (fig. 01).

SIGNIFICANCE AND CLASSIFICATION OF MIXED FIBER WASTE

As a result of the properties of petroleum-based synthetic fibers, such as polyacrylic, polyester, polyamide, etc., the following known improvements for textiles result from the targeted use of blends with natural fibers, especially with wool (Hofer, 1981):
- reduction of felting tendency
- increased wearing time
- lightweight fabric due to the low fiber density
- dimensional stability
- dries quickly
- good heat retention due to thermofixed crimped structures
- greater freedom of movement thanks to the use of elastane.

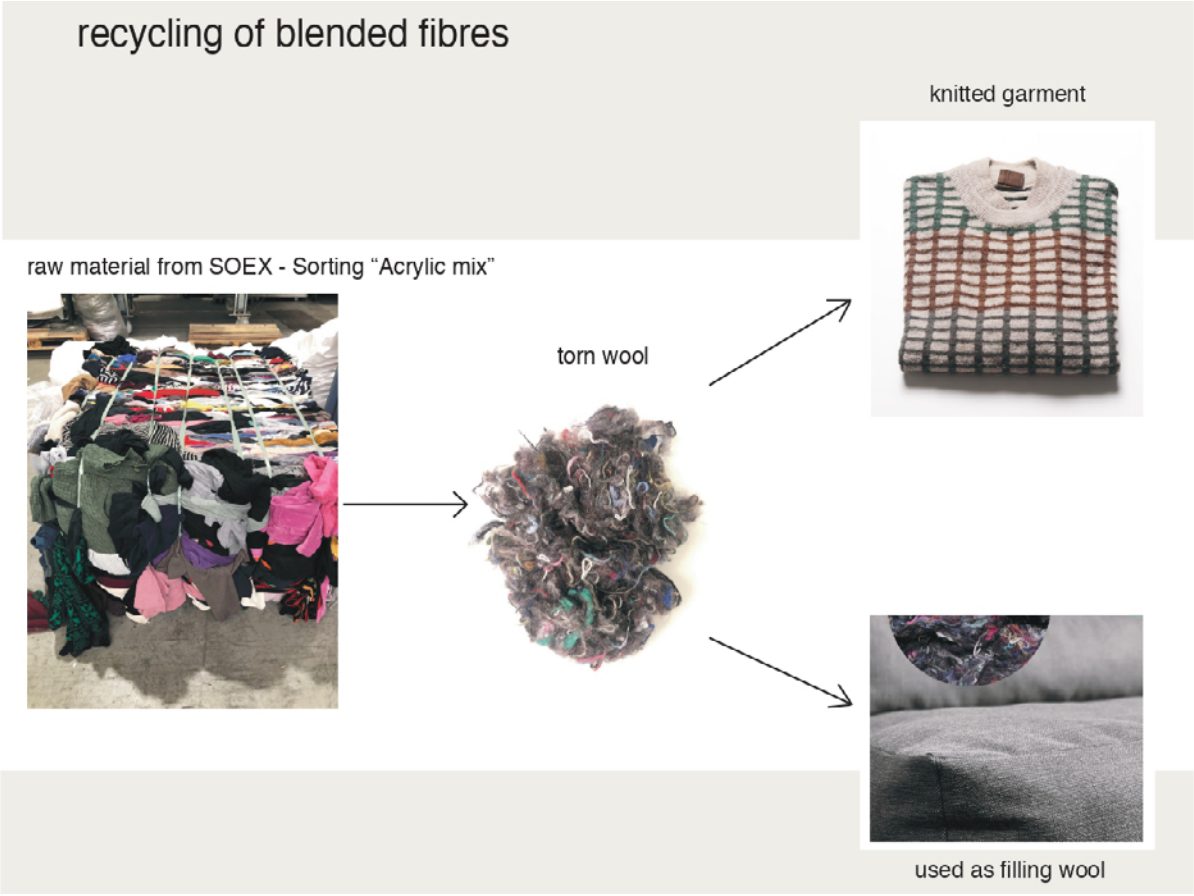

Fig. 01

With the property profiles mentioned, the wide range of synthetic fibers can be used in practically unlimited variations with natural fibers as well as mixed with each other.
Particularly in the area of leisure and sportswear as well as in the use of workwear and health clothing, blends with synthetic fibers have gained massive acceptance over the last few decades.
While fiber blends of natural and synthetic fibers were originally used to enhance the undesirable properties of the natural fibers, the natural fibers are now often added as alibi fibers in order to retain a natural component which, however, is hardly relevant for the textile properties due to its low admixture. These developments make it clear that future recycling steps in the manufacture of textiles have not been and will not be taken into account.
Systems and processes in the sense of the circular economy as it is described in the book Cradle to Cradle(Braungart & McDonough, 2021) as well as in the book Circular Design For Fashion (Ellen MacArthur Foundation, 2021) and the resulting design for recycling approach lead to a sustainable direction with regard to increased recycling cycles. Accordingly, the use of monofibers will play an important role in the future, as will the implementation of adapted recycling processes that take into account the current situation and the associated problems of multiple blends.
The variety of textile properties for our everyday demands on our clothing is not achievable through the use of natural fibers anymore, so synthetic fibers make a large part of our wearing comfort possible in the first place. The use of blended fibers in the apparel sector is a major driver for fast fashion for cost-cutting reasons. Here, the approach is to add natural fibers for the natural-looking character rather than to achieve special properties. This indifference of fiber blends leads to blend ratios of now standard three up to seven components within a garment.
If one considers the fact why synthetic fibers are used so indefinitely in blended fibers in terms of their modified properties, the essential question is why synthetic fibers are separated, especially in the chemical recycling process, than to use their properties within the existing blends, in which they were originally used for.
In order to achieve recycling of these blends for the clothing sector, the areas of sorting and the cutting-tearing process in mechanical recycling are analyzed and modified in this research project.

RECYCLING

The current state of the art in recycling is very diverse. The recyclability of monofibers and blends with a high proportion of natural fibers is already established on the market and is increasingly being used in the reuse of new garments. Customer acceptance continues to grow and recycled fibers serve as a figurehead for sustainable clothing.
Various processes are used to recycle mixed fibers. Mechanical, chemical and thermal recycling are among the most commonly used processes.
Mechanical recycling is used in particular for pure wool and wool blends, whereby a high proportion of pure wool in the blends is currently a prerequisite for further yarn processing.
Chemical recycling is mainly used for cotton blends with petroleum-based synthetic fibers. Among other things, the starting materials are depolymerized, the basic structure of the original polymer is changed or the chemical compounds are broken down by decomposition reactions (Cherdron & Krichel, n.d.a). The HKRITA has been researching the field of chemical fiber recycling for polycotton blends since 2016 with the development of the "Green Machine" in cooperation with H&M (HKRITA Hong Kong Research Institute for Textiles and Apparel, n.d.).
In thermal recycling, the textile waste is thermally utilized, for example in a waste-to-energy plant, and thus used one last time to generate energy. (Cherdron & Krichel, n.d.b)

SORTING

The fine sorting of knitted synthetic fiber/wool blends and the cutting/tearing process define the starting material for recycled yarn in order to ensure process-stable spinnability and good processability in the textile surface.
According to two German used clothing sorting plants, Texaid (Böschen, 2016), and SOEX (Steckert, 2022), around 50% of the used clothing collected is reused and sold on in second-hand stores. The remaining 50% is recycled, of which 16% is processed for use as shredded fibers. With around 50,000 tons of used clothing a year being sorted daily by companies such as SOEX and Texaid, this equates to around 8,000 tons a year that could be used as a useful resource for the clothing industry. However, pure new wool is rarely found as a quality in those 16%. In contrast, large quantities of synthetic fiber-wool blends are produced as a waste product of the fast fashion industry. Above all, the existing multiple blends lead to a high loss of value. My previous investigations have shown that fiber blends with up to seven different fibers are in circulation within one piece of clothing, which are further processed into filling and insulation material. For the clothing industry, this resource has so far been considered unattractive or currently not yet usable, as it is hardly possible to derive consistent parameters for the further process steps for the tear fibers due to their unknown compositions. Torn fibers are therefore used as such and are no longer used in yarn production.
Until now, better qualities have been sent to sorting plants in Italy, Belgium or Eastern Europe to be used for wool or cotton recycling (Böschen, 2016). In Italy, in the Prato area, wool has been recycled to a very high standard for the clothing industry on an industrial scale for many decades.
Companies such as Manteco (Manteco, n.d.), Comistra (Comistra, n.d.) or Re:verso (re:verso, n.d.) process knitted textiles with a high wool content from post-consumer and pre-consumer waste, whose materials and machine parameters are partly known due to the pre-consumer waste content.
Pre-consumer waste, as production waste from the textile industry, differs from post-consumer waste, as the term for used clothing, in terms of the unmixed and mostly known material compositions (Maetschke, 1978).
Furthermore, only knitted used clothing with a high proportion of pure wool is processed. Cellulose-based fibres or impurities are removed via carbonization processes; used clothing with a too high proportion of petroleum-based fibres is not processed. This ensures stable yarn production by using a clearly defined starting material.
In order to counteract the given fiber shortening in the area of mechanical recycling and the associated poorer yarn properties, new fibers are proportionally added as support fibers. Further processing in the examples mentioned is often carried out with petroleum-based synthetic fibers in order to make the overall quality more tear-resistant and durable.

METHODS FOR DIFFERENTIATED SORTING WITH REGARD TO MULTIPLE BLENDS

Differences in properties of the often not clearly identifiable synthetic fiber-wool blends influence the spinning behavior. To achieve recyclability of these fibers within the clothing sector, the research

project will analyze meaningful subcategories in addition to the existing sorting, based on fiber compositions. These subcategories include knit structure, stitch size, yarn twist, and yarn quality. These parameters significantly influence both the separation and integration of the fibers in the textile surface. The higher the twist of the yarns, the more difficult is the fiber separation. Similarly, very dense knits complicate the separation process.
For the planned experimental series, two comparison bales of the article Acrylic Mix, each weighing approximately 500 kg from the company SOEX (SOEX Textil-Verwertungsgesellschaft m.b.H., n.d.), were analyzed. To ensure a repeatable processing, categories of preferred fibre mixtures from post-consumer waste were developed. Acrylic Mix consists of knitwear in a variety of fiber types, including both mono and multi-fiber materials. This fabric is primarily used for further processing into shredded fibers(Maetschke, 1978).
Shredded fibres include all fiber materials that are obtained by tearing, as a mechanical shredding process, from textile surfaces such as woven, knitted or non-woven fabrics, as well as ready-made textiles, such as used clothing.
The sorting, in preparation for the planned experimental series, was carried out in three steps:

1. Raw sorting by fiber materials, distinguishing between plant and animal fibers, as well as cellulose or petroleum-based synthetic fibers. All cellulose-based fibers (cotton, linen, viscose, lyocell, modal, etc.) were removed due to the significantly different fiber lengths and fiber properties compared to wool blend fibres. All wool fibers, both as mono-materials and within the mixtures with petroleum-based synthetic fibers, thus serve as the basic material for the experiments.
2. Fine sorting using existing labels: detailed analysis of the mixed fibers.
3. Sorting by stitch geometry: determination of the stitch count per length unit and area unit according to the German standard DIN EN 14971(DIN, 2006).

The results from the raw and fine sorting showed that the goods largely consist of 100% petroleum-based synthetic fibers or mixed fibers, while only 4% consisted of pure wool.
Post-consumer waste varies between summer and winter goods, and consequently, the wool content may change. The described sorting was carried out in March 2023, containing mostly winter goods..

CUTTING PROCESS

The calculated mean value for an optimum cut size of the knitted starting material does not currently take into account the stitch geometry of the knitted fabric.
The planned adaptation of the cutting process in relation to the stitch geometry will result in parameters for a more repeatable yarn production process that shortens the necessary fiber lengths as little as possible, depending on the knitted fabric for further recycling cycles. The preceding fine sorting based on knitting structure, stitch size and yarn twist is crucial for this.

DESIGN OF EXPERIMENTS IN RELATION TO EXISTING MULTIPLE MIXTURES

To ensure a more fiber gentle separation of the textile surfaces, the conventional multi-step tearing process is being questioned with the adjusted cutting method. To investigate the influence of the tearing on fiber shortening, a parallel experiment excluding the process stages of tearing was conducted. The separation down to single fibers was carried out exclusively on the carding machine.
The following experiments were conducted for wool and polyacrylic fibres as mono-material and in mixtures:

1. Cutting and carding (cut sizes: 6x20mm, 13x30mm, 20x40mm)
2. Cutting, two tearing passages, carding (cut size: 50x50mm)
3. Cutting, four tearing passages, carding (cut size: 50x50mm).

By varying cutting dimensions and conducting several tearing passages, the degree of contamination of the carding rollers, the fiber dissolution, and the retention of fiber lengths can be analysed.
The execution of the previous experiments was carried out in collaboration with the Saxon Textile Research Institute and the Technical University of Chemnitz at the Institute of Textile Technologies and was developed at the laboratory scale on the following machines:

- Guillotine cutting system: R45 from Pierret Industries
- Tearing technology: Servo60 tearing machine from AUTEFA Solutions Germany GmbH
- Opener and carder: Ramella

RESULTS OF THE CUTTING PROCESS

In the current cutting process, the conveyor belt is loaded with the goods to be cut in several layers

disregarding the yarn direction. The resulting irregularly cut goods complicate the comparability. Therefore the knitted used clothing was cut open along the yarn direction across the conveyor belt. This allows the fibre length reductions to be calculated with regard to the stitch geometry.
With pure new wool, precise cuts in the desired cutting size were achieved with minimal deviations. Cutting trials with petroleum-based synthetic fibers, especially with wool-polyacrylic blends, revealed several challenges that significantly complicate further processing into yarn.
Elastane, being a highly stretchable fiber, is carried along with the cutting motion and is therefore hardly cut through resulting in large textile surfaces remaining as perforated but not cut goods (fig. 02).
For both mono-material and mixtures of polyacrylic fibres, the cutting resulted in majorly melted edges (fig. 03).
The heat is generated by the friction between the metal surfaces during the cutting movement. This can lead to the formation of neps in the torn fibers.
In addition to fiber shortening, nep formation is another problem occurring in mechanical recycling, which leads to inconsistencies in processing steps following(Kugler & Liebhold, n.d.). A precise cutting result without melted edges is therefore crucial for fiber separation.
In large recycling facilities, the tearing passages are directly linked to the cutting system, resulting in shredded fibers as the final product. In this state, the resulting melt edges are not visible. To what extent these affect the spinning process or whether this factor is irrelevant for further processing will become apparent during yarn production. These experiments are planned to take place in 2025.

CONCLUSION

The European Green Deal and extends the previous Ecodesign Directive to almost all types of products placed on the market within the EU. The aim is to strengthen the circular economy and extend product lifetimes. In particular, reprocessing and recycling are named as target-oriented measures.
As long as the industry is undergoing this change, it is important to continue researching solutions that take our currently available resources into account. The extent to which fibre blends can be processed economically and ecologically in the future must be further analysed.
The research approach presented takes into account the resources currently available, even if this means working on solutions for the fast fashion problem and the associated multiple mixtures. It was important to consider the interlinked processes in the industry separately and to evaluate their results individually in order to be able to modify them in the next step.
This was particularly important in the area of sorting. The current shredded post consumer waste is of inferior quality and is therefore still used far too little for the clothing industry. This process step was significantly improved by the three-stage sorting method described above.
Furthermore, problems were identified in the conventional cutting process, which can lead to significant impurities and associated irregularities in yarn production.
In initial yarn trials, correlations between the stitch geometry, the cut length and the resulting fibre shortening have already been established. The final results as well as comparisons with different yarn production processes are planned for 2025.By working closely with partners from industry from the outset, this research was intended to facilitate the transfer of results to an industrial scale.

Fig. 02

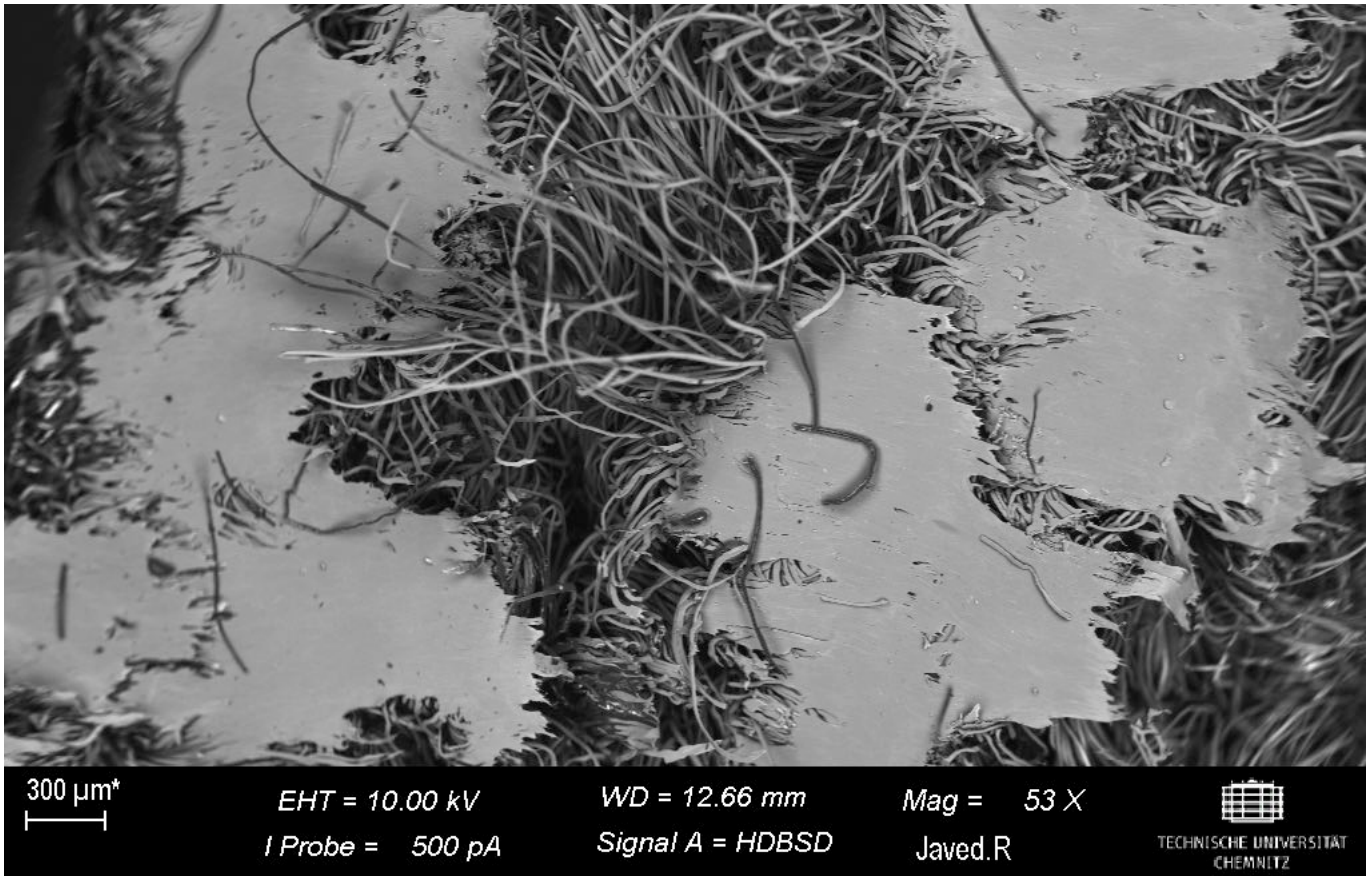

Fig. 03

All experiments were conducted on lab-scale machines modelled on the larger equipment used in recycling and yarn production.
This research connect design and engineering research questions to create more sustainable solutions for the clothing industry with an holistic approach.

CAPTIONS

[Fig. 01] Post- Consumer-Waste – upcycling vs. Downcycling strategy: Magdalena Kohler

[Fig. 02] Stitch Geometry of the knitted Post-Consumer-Waste: Magdalena Kohler

[Fig. 03] Cut result of a wool blend with elasthane: Magdalena Kohler

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