Fractionating Complex Multicomponent Textile Fibres Waste

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Final Report

By

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1 Background

The objective of the project was to develop a novel mechanical process for the fractionation of the multi-component blend of textile fibrous waste, to enable the value-added recovery of high-value polymers from such wastes; we are very thankful to Åforsk for the financial support of the project.

The textile sector uses a very large quantity of raw materials and produces a substantial amount of waste. This is partly because, currently, only a small amount of wearable textiles is recycled. Most of these textiles are landfilled or incinerated, with a high negative environmental impact and large quantities of valuable resources lost. Most of the waste fabrics are currently disposed in landfills, costing on average more than $30 million on disposal costs alone, which does not account for the cost of handling and shipping. The municipal textile consists of approximately: PET polyester 45%, Cotton 41%, Polyamide PA6 5%, Wool & Silk 2% and other minor components e.g. spandex, polypropylene etc at less than 1%.

Textile waste treatment strategies include reducing, reusing, recycling and energy recovery all with a focus on doing less harm.

Recycling of textiles to lower quality products (downcycling) is not very challenging, as the products require less stringent compositional and mechanical properties. In order to recycle textiles into higher quality products (upcycling), pure component fibres are needed. It involves a precise identification and sorting, which is not possible at the moment (50% of textiles are made from fibre mixtures). There is a need to demonstrate that existing sorting and recycling technologies can be combined for an effective recovery of fibres and/or their building blocks and conversion into high-value feedstock.

The proposed strategy develops a novel approach using mechanical techniques as opposed to melting recycling or chemical technique, to enable the value-added recovery of high-value polymers from such wastes.

2 Summary of the results in AP1 surface modification of fibre

In staple fibre processing, low fibre/fibre cohesion facilitates easy separation of the fibre bundle during the opening process. Lubricants are referred to as substances that minimize cohesion; hence it is necessary to investigate the effect of lubricant.

2.1 Measuring the fibre/fibre cohesion

The need to develop the fibre/fibre cohesion test method is essential to evaluate the effect of different lubricants and percentages in reducing the fibre/fibre cohesion.

The developed method of measuring fibre/fibre cohesion is based on the tensile tester of fibre webs; a carding machine can produce this web (Fig. 2). During the tests, it was observed that at point A, the web begins to stretch up to F_{max}.

At this point, the fibres start sliding past one another until they are almost completely separated. From the two curves, we can distinguish that cotton has a higher fibre/fibre cohesion, which was attributed to the difference in surface morphology and geometry of the fibres.

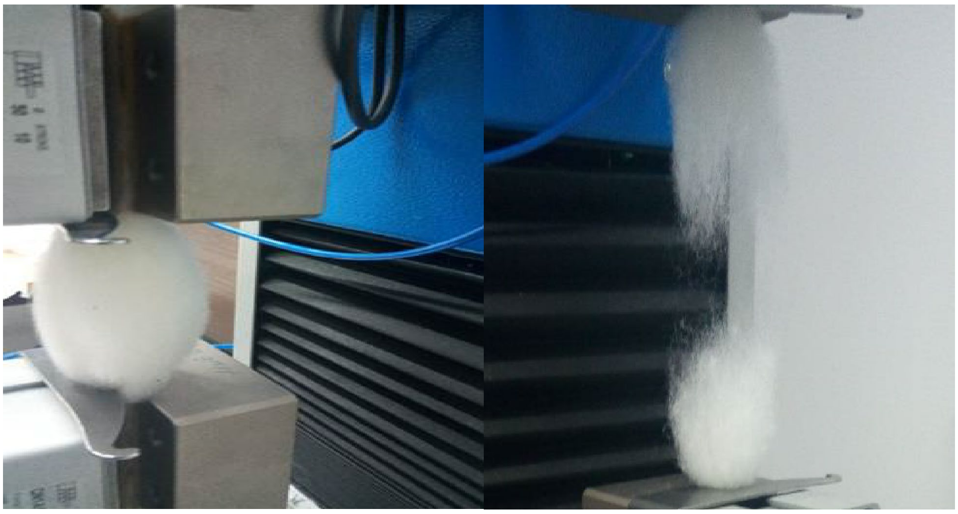


Fig. 1. Friction test by tensile test of web

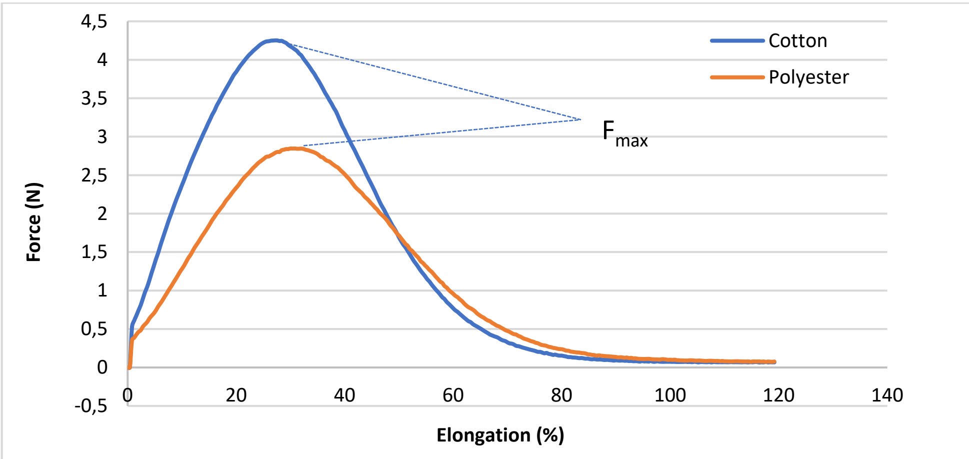


Fig. 2. Load elongation curves of untreated cotton and polyester fibre webs.

2.2 Effect of lubricant on the fibre/fibre cohesion

Investigation of the internal friction of fibre to fibre after the treatment by different lubricants:

- PEG (Polyethylene glycol) can be used as a textile lubricant and is well known as non-toxic, cheap and recyclable.
- Another commonly used lubricant is glycerol. It has been used for various applications, including textiles. It has been utilized successfully as a lubricant for a variety of fibres during yarn and fabric processing. Glycerol is a green solvent just like water, cheap, non-toxic, readily available and recyclable.

For the fibre, a cotton fibre with 25mm length, and staple polyester fibre with 51mm length and 2.0 Denier for linear density. For finishing treatment, we had used three types of materials (Table. 1).

Table 1. Specifications of Finishing treatments used

Symbol	supplier
Polyethylene glycol (PEG)1000	Merk KGaA
Polyethylene glycol (PEG)4000	Merk KGaA
Glycerol	Merk KGaA

The results of the application of lubricants on cotton fibre webs are presented in (Fig. 3). Three types of lubricants are used PEG1000, PEG4000, and glycerol with different concentrations. These results show that the pre-treatments affect the fibre/fibre cohesion, and the PEG4000 had a high effect on the reduction of fibre/fibre cohesion with a treatment amount of 0.2%

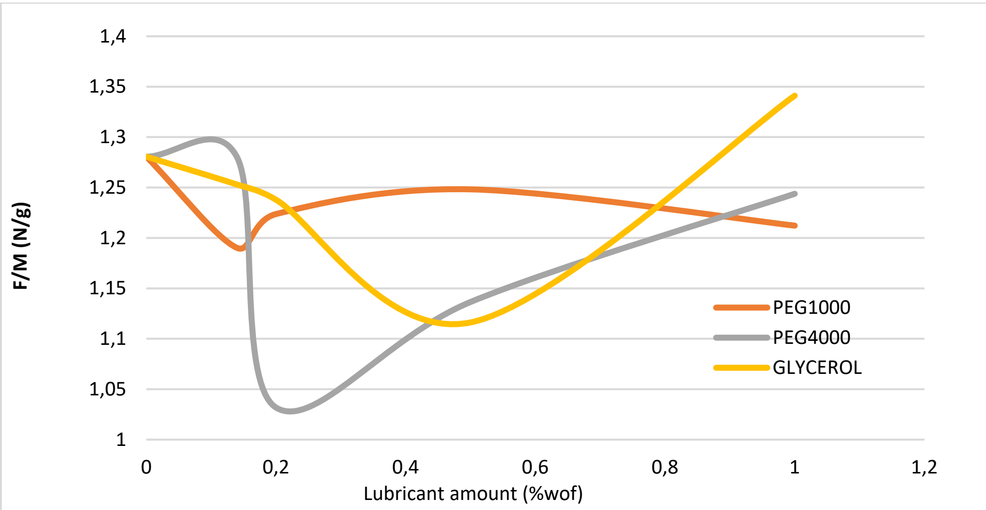


Fig. 3. Variation of fibre/fibre cohesion for treated cotton.

Similar fibre/fibre cohesion results were obtained for treated polyester fibre with the same treatment and the same percentage. These results show that PEG4000 had a high effect on reducing fibre/fibre cohesion with a treatment amount of 0.5%.

The results of AP1 was submitted to the Journal of Engineered Fibres and Fabrics.

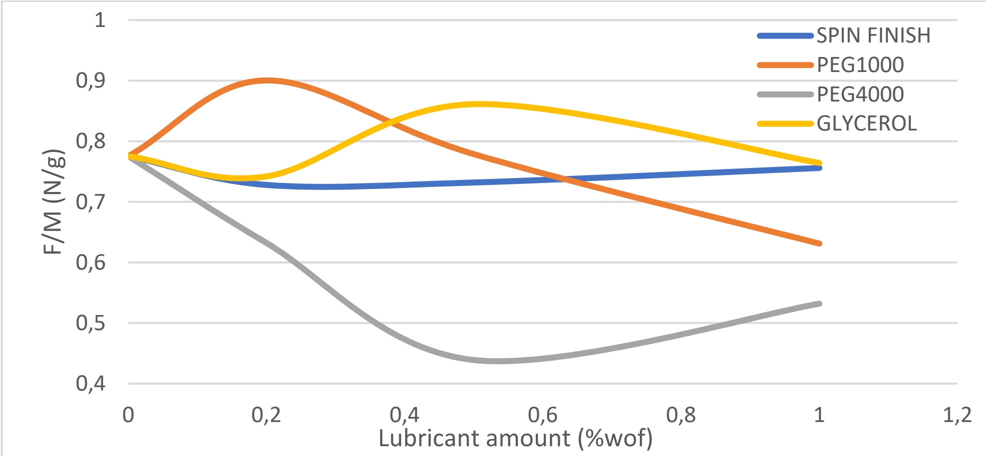


Fig. 4. Variation of fibre/fibre cohesion for treated polyester fibre.

3 Summary of the results in AP2 acoustic radiation force

The application of the acoustic radiation force was made in a bath of water mixed with a specific percentage of lubricant, where some parameters can affect the results, like the quantity of water in the bath related to the fibre length used.

3.1 Effect of fibre length related to bath volume:

The pre-testing showed an effect of the bath volume on the fractionation results. For that, we started to investigate the size needed and their relation with fibre level.

We have investigated the minimum quantity of bath volume where the fibre can individualize, we have used for testing polyester fibre 3,5Dtex with a cutting length of 2 mm, and we find that 1gr of fibre we need a minimum of 5 litres of water

Another parameter investigated is the fibre length; for that, we had used polyester fibre 3,5Dtex with a cutting length of 2, 5, 7 and 10mm cutting. The results show that we had a relationship between the fibre length and the bath volume needed. This volume needed for each fibre is related to the square length of the fibre. And we can use the following experimental equation:

$$V_b = \frac{5}{2^2} L^2$$

V_b is the bath volume in litre for one gr of fibre, and L is the fibre length in mm.

3.2 Fractionation of polyester/Polyamide mixer:

White PA12 Flat yarn 220Dtex and black polyester textured 167Dtex, with 5mm fibre length cutting, was used for the testing; the fibre was mixed using the carding process three times to ensure the homogeneity of mixing.

Fig. 5. polyester/Polyamide fibre mixer

Two types of baths were used, with water only and water with (0,4 %wof) PEG4000. For ultrasonic, we had used UP400St from Hielscher.

The results that the fractionation by using the water only wasn't successful (Figure 6)

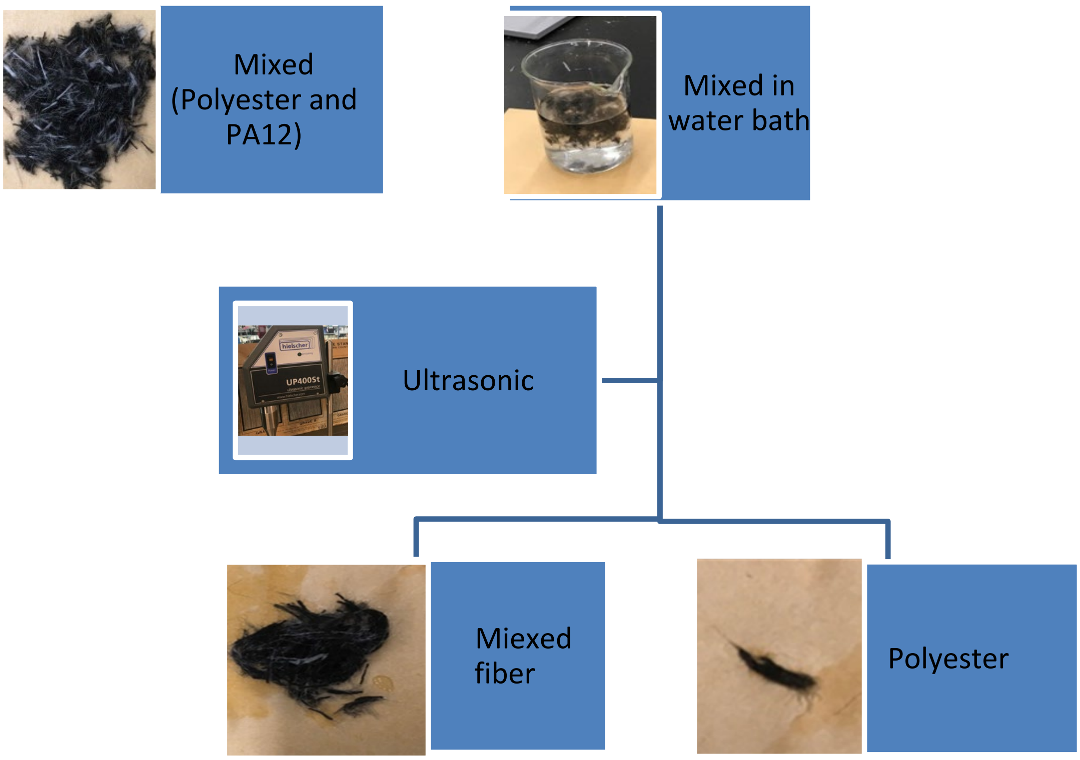


Fig. 6. Fractionation polyester/Polyamide fibre mixer in the water bath

The results that the fractionation by using the water with PEG4000 give good results, For the first round, we were able to fractionate successfully 65% of fibre weight (Figure 7)

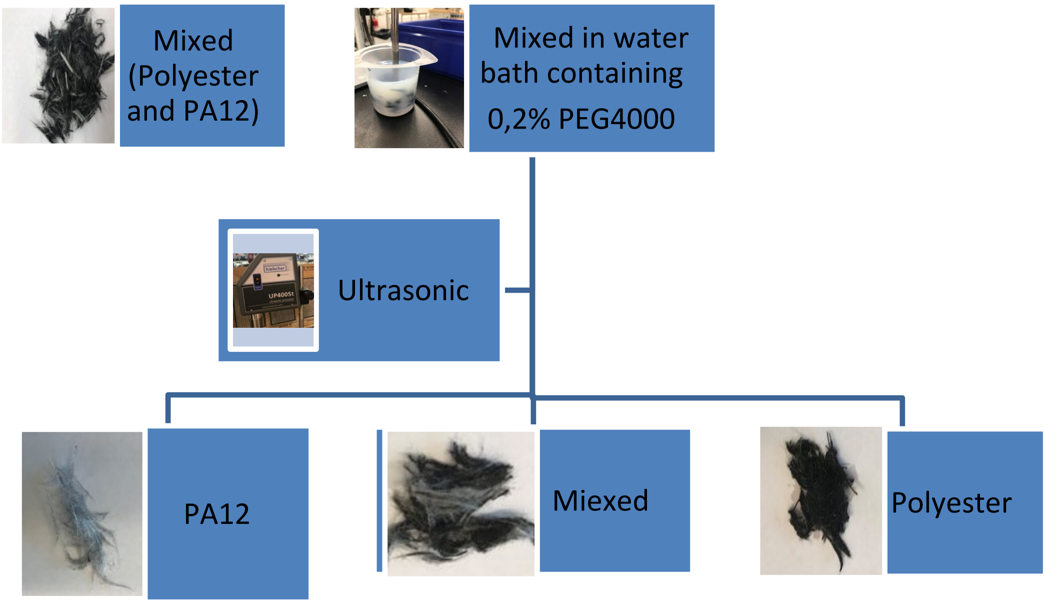


Fig. 7. Fractionation polyester/Polyamide fibre mixer in the water bath with PEG4000

It is worth mentioning that we had tried to do the fractionation in a dry condition where we had sprayed the fibre with PEG4000 (0,4 %wof) and used LPx from Branson to produce an ultrasonic wave with 40 kHz frequency, the results not so promising.

A paper about these results is underwriting.

3.2.1 Fractionation of cotton polyester mixer

The used material was 50% cotton and 50% polyester with a cutting length of 5mm; the fractionation tests were done in a water bath containing PEG4000. Three concentrations of PEG had been tested 0,2 – 0,3 and 0,4 %wof.

We had used UP400St from Hielscher to produce the ultrasonic wave; All the tests failed, and we could not fractionate them (figure 8).

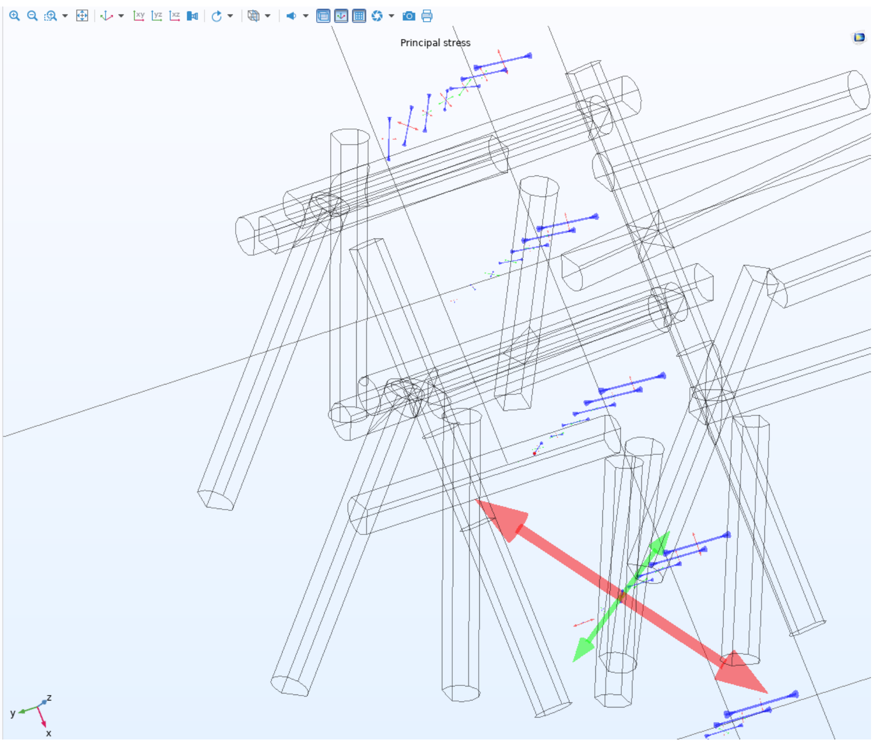
Thus, we conclude that cotton fibre needs more in-depth surface modification or associate this method with other techniques like biological and/or chemical treatments.

Another point we have distinguished during the test is the effect of frequency and energy on the cellulose. For that, we did several tests by using several sources of energy; we found an effect of Microwave energy on the cellulose fibre. This result was published in Fibres journal.

4 AP3 Simulation

We have used the COMSOL Multiphysics program to simulate the effect of ultrasonic waves on fibre fractionation in a bath of water. Where we had different stress and the fibre's surface with a focus on the principal stress (figure 9).

The simulation results and experimental results did not match. This is related to the fact that we hadn't been able to simulate the effect of fibre contact surface with correct parameters during the simulation. More research about this simulation needs to be conducted to find a solution to introduce the contact surface properly in the simulation.



5 AP4 Prototyping and testing

The results were not as successful for all types of fibres, especially for the cotton fibre, where we were not able to fractionate the polyester/cotton blends.

Therefore, we have conducted a comprehensive bibliographic study to develop the method and to check the other possibilities. These possibilities include combining mechanical, biological and chemical treatments within ecotechnologies. These steps are expected to contribute to the reduction of: power consumption, chemical/ biological materials. Furthermore, using non-toxic or recoverable materials while reducing the waste produced during the process.

Although the topic of fractionation of fibres is still challenging at both laboratory and industrial scales, we see potential in pre-treatment of fibres with lubricants to facilitate the mechanical separation of fibres while maintaining the best quality possible of these fibres, so they can be upcycled as shown by our results. The additional and optimized biochemical methods via enzymes and other catalysts, which are highly selective materials and work on lower temperatures, enabling an economic and ecological recycling process without the undesired side effects to the quality of fibres.

Chemical treatment (via ionic liquids and other materials such as organic solvents) that can dissolve or depolymerize the components of the polymers to regain the basic monomers in order to reprocess them again is a big topic that is worth discovering as an assisting step to mechanical fractionation. The main advantage of some ionic liquids over other chemicals such as organic solvents, is that they can be recovered/ reused in high efficiency during the process. Therefore contributing to the sustainability and circular economy aspect of this fractionation process. There are few recent studies and projects on this topic in the early stages (Coin TEX2MAT and RESYNTEX projects), but it is still considered as a big gap to be filled with innovative and feasible ideas to solve the huge global issue of blended-textile waste.

Since the recycling process needs to be profitable in general, a bonus-malus system based on producer responsibility should be considered as well. A system like that could raise collection rates of blended-textile waste, and subsequently also recycling rates by making their implementation economically feasible.

Some challenges that are still facing the recycling of the textiles (made from one type or blended fibres) that need to be addressed as pre-treatments in some cases, such as the removal of dyes, pigments, finishing materials such as fire retardants agents and water proofing agents from the textiles. These steps consume energy and additional chemical or thermal treatments prior to the separation and recycling processes.

Additionally, even for the textile waste that is made from the same type of fibres, the sewing threads are usually different from the fabric in general and require additional care in separation.

It is worth mentioning that textiles go through partial chemical and mechanical degradation of their material due to laundering and use, in addition to more fibre stiffness due to physical aging. These changes result in shorter polymer chains and less tensile strength due to chemical aging, and that needs to be addressed in any recycling or upcycling methodology.

Finally, the lack of sorting mechanisms (mostly done manually) to identify textiles from different sources requires more innovative methods to facilitate the collection and the later processes.

6 Conclusions

A new testing method for measuring the fibre/fibre cohesion has been developed by using a tensile testing machine.

It was found that, cotton has higher inter-fibre friction than polyester fibres and this was attributed to the difference in surface morphology and geometry of the fibres.

The treatments affect the fibre/fibre cohesion properties of cotton and polyester fibres, and PEG4000 had reduced this cohesion.

The fractionation by ultrasonic polyamide/cotton by water-bath with PEG4000 gave good results; For the first round, we were able to fractionate successfully 65% of fibre weight.

The mixing of cotton/polyester was not able to be fractionated, where the need to associate another technique is worth studying.

The simulation by finite element needs to be improved by introducing the correct contact surface parameters.

7 Publication

1- Syrén, F.; Peterson, J.; Kadi, N. Effects of Microwave Treatment in Immersed Conditions on the Mechanical Properties of Jute Yarn. Fibres 2021, 9, 40. https://doi.org/10.3390/fib9070040
2- Katarina Lindström, Nawar Kadi, Anders Persson, Lena Berglin. Development of an inter-fiber cohesion test method for staple fibers using a tensile tester, Journal of Engineered Fibres and Fabrics. "submitted."
3- May Kahoush and Nawar Kadi, Fractionation of textile waste – Advances and prospective, Journal of Cleaner Production, "submitted."

Acknowledgement

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