MINSHED

Design solutions for microplastics shedding from textiles

Anne-Charlotte Hanning, anne-charlotte.hanning@ri.se, RISE
Rebecka Landin, rebecka.landin@ri.se, RISE
Sebastien Rauch, sebastien.rauch@chalmers.se, Chalmers University of Technology
Steffen Schellenberger, steffen.schellenberger@ri.se, RISE
Christina Jönsson, christina.jonsson@ri.se, RISE
SUMMARY

Microplastics emissions is complex issue with a vast variety of influencing parameters through a textile's life cycle. It is evident that all parts of the value chain need to cooperate and take their responsibility.

The studies in this report shows that one cannot generalize. Fleece is not automatically worse than plain weaves or knitted fabrics. Another myth that is that recycled fibres are always worse than virgin fibres - which results in the MinShed project show is not true.

When testing fabrics, the first wash always shows the largest amount of microplastics. This indicates that manufacturing steps can have a large impact, examples investigated in MinShed are cutting techniques and finishing treatment. The overall working environment in the production facility and wastewater management is not to be forgotten either. One conclusion is that an adjacent wastewater treatment at the textile production facility is a way to significantly reduce the microplastic emissions.

The real-life study by Chalmers University of Technology showed that wearing the textiles have a significant impact on microplastics emissions. Fibre emission was consistently higher for all worn garments compared for unworn garments after five washes. Hence, results indicate that previously reported emission rates measured on unworn clothes may underestimate the emission under real-life conditions.

Washing is probably not the largest contributor compared to manufacturing steps. However, the washing cycle is still a significant point source for microplastics entering the wastewater. From a consumer point of view, there are some measures which will help to mitigate generation of microplastics. This includes the choice of washing program and how to load the machine. There are also several commercially available filter products which, to some extent, can help to mitigate the microplastics emissions.

From a washing machine manufacturer point of view, the washing programs are difficult to optimize for just mitigating microplastic emissions since the function for a washing machine is to clean textiles. It is also difficult for a manufacturer to control consumer habits. The largest impact for mitigating emissions will most likely be to integrate a filter in the washing machine for filtering the outlet effluent. Clogging of filters can pose a problem depending on the detergent and dosage.

There is not enough knowledge yet for a complete guideline. For a brand producing synthetic products, it can be a good idea to start a dialogue with the manufacturing facilities to investigate improvements regarding for example, cutting techniques and wastewater management. Regarding design choices, there are still many knowledge gaps. A general recommendation is to avoid or minimize severe mechanical and /or chemical treatments. One parameter that is not to be forgotten, is the overall quality of the textile.

The outreach has included a wide range of activities. An information brochure is
published, several presentations of the MinShed project and findings - both national and international. Invitation to OECDs workshop on microplastics. Stakeholder meetings at EU level. Several measures of mitigating microplastics emissions are currently investigated at EU level which the report briefly gives information about.

One very important outcome from the project is the validated standard method DIS /ISO 4484-1 Textiles and textile products — Microplastics from textile sources — Part 1: Determination of material loss from fabrics during washing. This will be the key to unravel the existing knowledge gaps.

A critical review of published literature investigated traceability within in the textile area evaluating microplastics emissions during washing. The result from this thesis was that only 2 out of original 52 articles had full transparency.

Another thesis focused on investigating toxicity of a selection of textile additives and environmental pollutants that have been observed to sorb onto microplastics. The risk analysis calculation shows that there is no risk to humans to exceed Tolerable Daily Intake level (TDI) of the investigated chemicals. Since this research field is rather new and associated with a lot of uncertainties, more research is required to confirm these findings.

Microplastics emissions as a vector for chemicals was closely followed in the study of fluor emissions originating from the microplastics emissions of washed fluorinated DWR treated fabrics. The result suggests that on the European scale, these are low emissions estimates in comparison to global emissions estimate for PFAAs released during the life cycle of consumer products.
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2. BACKGROUND

Microplastics pollution of marine environment is an environmental issue which has been intensely discussed on a global level. The cause behind the increasing amount of microplastics in marine water bodies is not fully known, though some of the few studies made so far point to household washing of textiles as a major contributor [1, 2].

Previous research activities on this topic focused of distribution of microplastics in the coastal and marine environments as well as environmental effects of microplastics on animals and plants [3-5]. Several studies have found that textile fabrics do shed microfibres [6-9]. However, a research gap has been identified regarding the link between fabric construction properties and microplastics emissions, as well as studies on design solutions for fabric construction and washing machine filters [10].

From the industry perspective, the textile industry and its stakeholders lack scientifically based guidance both on how to construct garments to minimize and avoid microplastics emissions and on what advice to give to customers regarding textile care.

Goal and scope

The goal of this development project was to provide scientifically based solutions for mitigation of microplastics emissions. Although, since reliable results only can be achieved if using a standardized method, this became the prioritised subject. Without the presence of a standardised method, it would be impossible to compare results and draw any reliable conclusions.

The aim was to improve the In-House method, compare the results with other initiatives in the field, with the expected outcome that a standardised method could be established.

In addition, the communication and collaboration within the microplastic area was highlighted to have a big part where the goal was to share new information with the industry and the consumers.

Potentially hazardous chemical content of textile fibres is another issue of importance where knowledge is lacking. Therefore, one study concerning the release side chained fluorinated polymers was closely followed. In addition, a bachelor thesis evaluating toxicity in conjunction microplastics was also performed.

Limitations

Distribution and environmental effects of microplastics are areas outside the research scope, though on-going research in these areas are followed. Optimization of detergents is not studied.
3. INTRODUCTION

When the project started, there were no standardized method available for assessing microplastics emissions from synthetic textiles or any ongoing standardization work in either CEN or ISO. But several organizations had an In-House method - as did RISE. At the same time the initiative Cross Industry agreement (CIA)[11] started up where RISE was invited to join. It was through this voluntary international collaboration the work with developing an international validated standard method was conducted. Hence, one important part of the project was dedicated to contributing to this work.

The following parts were included in the project:

1. Development of harmonized standardised test method.
2. Results concerning impact of different constructions and manufacturing steps, laboratory trials as well as a real-life study.
3. Filter solutions and impact of washing parameters
4. Outreach – communications activities and policy work at EU level
5. Health impact – microplastics as vector for hazardous chemicals

First insights concerning fabric constructions, type of fibre (virgin versus recycled polyester) and impact of different production steps is investigated in chapter 6. In chapter 8 different filter solutions for domestic washing machines were tested. This was followed up in chapter 10 looking into impact of three washing process parameters: time, temperature and water level. The real-life life study comparing washing & drying versus including real-life wearing to washing & drying is found in chapter 10.

Regarding outreach, the MinShed project and results has been presented at a wide range of activities, both national and international. A brochure [12] has been published with information about background, current knowledge and research gaps, but also myths and facts about microplastics emissions from textiles. Ongoing policy work on EU level is briefly described.

Referring to part 5, it was decided to briefly look into microplastics as a potential health risk. This is investigated in chapter 7 in the thesis “Microplastic polyester fibre as a source and vector of toxic substances: Risk assessment and evaluation of toxicity”.

Another study that was closely followed examined the effects of materials that were chemically treated with Fluorotelomer-based polymers (FTPs) and if the microplastics derived from these materials might be a vector for hazardous chemical pollutants.
4. OUTREACH

Microplastics release from textile has been an engaging issue over the last years. When the MinShed project started there were at least 52! different initiatives and projects just started/on-going in Europe.

To be able to be somewhat updated one important part in the project was to reach out and to share experiences and findings. For example: “Textile Mission” in Germany, “Microfibre” in Norway and “Fibreclean” in Spain. In that spirit RISE visited Sintef [13] in Norway who led the project “Microfibre”, however with another angle than MinShed. Nevertheless, it led to both projects using the same testing material in some of the early trials which was very useful in the beginning of developing the test method.

There are a lot of rumours and myths concerning microplastics release from textiles. One important task in MinShed was to inform about these false statements and well as scientific findings.

National presentations were made for example at “Textildialogen- theme microplastics” and at meetings with the network The Chemicals Group (approximately 120 Nordic textile member companies) and West Sweden Chemicals and Materials Cluster. An open breakfast seminar was arranged by Johanneberg Science Park. Example of international presentations are the fair ISPO - Munich in 2019 and the OECD workshop on microplastics in 2020.

RISE also engaged in the initiative Cross Industry Agreement (CIA)[11]. The CIA initiative is a voluntary collaboration for the prevention of microplastic release into the aquatic environment during the washing of synthetic textiles. The signatories are five European industry associations representing the global value chain of garments and their associated maintenance, namely AISE, CIRFS, EOG, EURATEX and FESI. Research organisations, universities and laboratories working with the microplastics issue were invited to collaborate with the aim of developing a validated international standard for assessing microplastics release from textiles during washing.

In addition to the international work with a new standard method, RISE was also involved in in developing an information brochure “For the prevention of microplastic release into the aquatic environment during the washing of synthetic textiles” [12]. The content includes background, current knowledge and research gaps, but also myths and facts, see Figure 1. The brochure has been distributed to the MinShed partners and is available for download in three languages (English, Japanese and Chinese) at the EURATEX website [14]. In addition, there is a FAQ regarding the CIA test method (the same method that was submitted to ISO/CEN), also available at the EURATEX website.
Through the MinShed project and the CIA initiative, RISE is also collaborating with The Micro Fibre Consortium (TMC) [15] which originated from the European Outdoor Group (EOG). TMC is a non-profit organisation with the aim to prevent fibre fragmentation from textiles. One outcome is recommendations for mitigation of microplastics emissions at production facilities, see page 31-32.
5. METHOD DEVELOPMENT

In a textile manufacturing process, a long series of steps take place, all of which can play a role regarding microplastic shedding. First, a fibre is required that can be spun into a yarn, that is twisted in different ways along the fibre axis. With the yarn you can produce a fabric through weaving or knitting. Before the fabric is manufactured into a garment there are usually a series of finishing processes to achieve right aesthetic and functional requirements. Then the fabric can be cut and sewn into a ready-made garment.

In all manufacturing steps, microplastics will be released in different amounts. In addition to the microplastics released during manufacturing, a large part will also be released during the use phase. The Figure 2 below describes different phases where fibre release can occur.

However, there has been a lack of information and knowledge about how different design parameters or manufacturing processes can affect the total fibre fragmentation. Also, it is not possible to compare results from previous studies in the area as no harmonized method for measuring fibre release has been available. Which in turn led to that no accurate conclusions could be drawn in the matter of the amount of fibre shedding from domestic washing.

Since a standardised method was required to draw reliable conclusions, a lot of effort were put into method development.

In parallel to RISE early work, a new international initiative called Cross Industry Agreement (CIA) hosted by EURATEX[14] was initiated during 2018. Due to the RISE
paper on method development [16], RISE was contacted and invited to join. The first task was to compare all partners in-house methods to see which parameters were the same, or almost the same, and which were different. Most of the partners used EN ISO105-series (method for assessing color fastness) as basis for a laboratory method. The equipment for performing these assessments is also well known by laboratories and brands. The decision was made to continue the development with EN ISO 105-series as a basis. Other decisions that were made include no expensive cutting equipment and that the method must work for both synthetic and natural fibres. These decisions were made to get the best spread, taking in consideration that also brands should be able to perform the method. More comprehensive information regarding the method development, see the following subtitles in this chapter.

**Early method development**

First, to get ahead with the work with the method, more development and improvements to the in-house method were realized after combining experiences from previous work [16]. In the early method development, there were some obvious differences between the RISE in-house method (RISE 2019) and the University of Leeds method, see Table 1. Both methods were based on the ISO 105-C12:2006 standard, originally used for color fastness assessment. Besides this, there were a lot of different steps regarding sample preparation, wash cycle time and analysis method. Therefore, it was agreed that a comparison was necessary to perform, where the two methods could be evaluated to discover and investigate possible differences in the results. The comparison was done through a Round Robin together with University of Leeds.

**The University of Leeds method vs RISE 2019**

During the method development and comparison, the same fleece material, Fleece A, has been used for all fabric samples unless otherwise specified.

In the University of Leeds method, a fleece material was used and cut to rectangles with the size of 270 x 130 mm. The edges of each specimen were overlocked, 15 mm folded and stitched in place. Before and after wash each specimen was individually weighed after 4 h in a conditioned controlled environment. The wash was carried out in closed canisters with one fabric specimen, 360 ml of distilled water and 50 steel balls in each container without detergent. The accelerated washing was kept at 40 degrees Celsius for 60 minutes. In total each of the specimens were washed three times and the resultant liquid from each wash was vacuum filtered to. The material loss then was assessed gravimetrically.

The RISE 2019 method instead used a welded fabric bag as a test specimen, filled with 25 steel balls. The size of the fabric samples also differed, 190 x 90 mm instead of 270 x 130 mm. The University of Leeds weigh each specimen prior to washing and after each wash cycle. The wash liquid was then filtered, and the filters was weighed before and after filtering to be able to see the mass of the released fibres. The RISE 2019 did not use mass to determine shedding, instead a light microscope with special designed software was used to automatically quantify the number of shed particles and fibres.
Table 1 Differences between the RISE 2019 test method and the University of Leeds method.

<table>
<thead>
<tr>
<th>Process</th>
<th>RISE 2019</th>
<th>University of Leeds Round Robin 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample preparation</td>
<td>Welded edges</td>
<td>Overlocked edges</td>
</tr>
<tr>
<td></td>
<td>5mm edge folded twice</td>
<td>15mm edge folded once</td>
</tr>
<tr>
<td>Wash cycle time</td>
<td>60 min</td>
<td>45 min</td>
</tr>
<tr>
<td>Filter size and type</td>
<td>90 mm membrane filter</td>
<td>47 mm glass filter</td>
</tr>
<tr>
<td>Method of analysis</td>
<td>Filtering 5% of wash liquid,</td>
<td>Filtering 100% of wash liquid,</td>
</tr>
<tr>
<td></td>
<td>counting fibres on filter</td>
<td>weighing the fibres on filter.</td>
</tr>
<tr>
<td></td>
<td>using microscope and software</td>
<td></td>
</tr>
<tr>
<td>Rinsing fabric sample when</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>separating from wash liquid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditioned environment</td>
<td>Yes, 4 h prior to and during</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>weighing</td>
<td></td>
</tr>
</tbody>
</table>

The first part of the method development investigated pre-treatments. The University of Leeds did not perform any pre-treatment of the fabric samples to remove any contaminants originating from production etc. Earlier in-house methods at RISE described a pre-treatment using a vacuum cleaner to remove dust and loose fibres on the fabric surface. But, since questions raised around how to ensure the repeatability using a vacuum cleaner, only vacuum cleaning as pre-treatment was discarded. In the thesis “Fibersläpp från polyester i tvätt” [17], this was further investigated by placing the fabric in a fixture when vacuum cleaning. Conclusions were that the fixture reduced the statistical dispersion of the test results. However, the results showed an interaction between the material, the person vacuuming and the power of the vacuum cleaner, making it inadvisable to use as pre-treatment, fixture or not. The thesis work was carried out through collaboration between RISE and the Swedish School of Textiles at the University of Borås.

Instead, another method was evaluated where a pre-rinse in the Gyrowash equipment [18] was used to reduce contaminants and water-soluble compounds in the fabrics. This also allowed filtering of the rinse cycle-liquid and the possibility to identify these contaminants.

The second part of the method development was to determine whether to continue using a bag or to use a flat/plain sample. Tests were carried out with an overlocked and sewn bag, using the same size fabric specimen as the University of Leeds.

Table 2 Mass in grams (g) on filters after rinse cycle and main wash.

<table>
<thead>
<tr>
<th>Sample no</th>
<th>Rinse cycle (g)</th>
<th>Main wash (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0013</td>
<td>0.0013</td>
</tr>
<tr>
<td>2</td>
<td>0.0018</td>
<td>0.0013</td>
</tr>
<tr>
<td>3</td>
<td>0.0020</td>
<td>0.0014</td>
</tr>
</tbody>
</table>
As seen in Table 2, the bags release less fibres and the range are narrower between the different replicas as compared to the flat fabric. The conclusion was that the mechanical action is more evenly distributed in the bag and the decrease in shedding was possibly due to only half of the surface being exposed.

Table 3 Mass loss in grams (g) of fabric sample

<table>
<thead>
<tr>
<th>Sample no</th>
<th>Rinse cycle (g)</th>
<th>Main wash (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hemmed flat fabric</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0,0060</td>
<td>0,0060</td>
</tr>
<tr>
<td>2</td>
<td>0,0074</td>
<td>0,0067</td>
</tr>
<tr>
<td>3</td>
<td>0,0143</td>
<td>0,0065</td>
</tr>
<tr>
<td>4</td>
<td>0,0110</td>
<td>0,0055</td>
</tr>
<tr>
<td><strong>Sewn bag</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0,0167</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0,0212</td>
<td>0,0044</td>
</tr>
<tr>
<td>3</td>
<td>0,0200</td>
<td>0,0023</td>
</tr>
<tr>
<td>4</td>
<td>0,0143</td>
<td>0,0015</td>
</tr>
<tr>
<td><strong>Welded bag</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0,0133</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0,0084</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>0,0126</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>0,0090</td>
<td>-</td>
</tr>
</tbody>
</table>

After the first comparison, a second test was performed where a welded bag in the same size was tested and compared to the sewn bag. The results differed from previous findings, and it was concluded that the fabric did not shed equally from both sides. Therefore, it was decided to use the flat sample style to eliminate any unequal shedding from face and back.

Next step was to evaluate the microscopic versus the gravimetrical analysis method. But, due to large amounts of fibres on the filters when filtrating all liquid, the microscopic analysis was difficult to carry out in a time efficient way. The need to be able to compare the methods led to that the microscopic comparison was cancelled and it was decided to focus on the gravimetrical analysis method in the comparison. The microscopic analysis method still came to be used when comparing materials in the MinShed project, where it was considered of interest to investigate number and size of different particles and fibre fragments.
The initial idea was to seal the edges of the fabric sample using an ultrasonic welding machine. Figure 3 shows an example of a welded edge and a fraying non-welded edge of a polyester knit after pre-rinse and wash cycle. But since the method must work for both different kinds of cellulosic and synthetic materials, the welding technique alone is not sufficient to seal the edges in every situation. The conclusion was that it is still preferable to seal the edges with traditional seams.

![Figure 3 Welded edge vs non-welded edge](image)

**Standardisation work in CEN/TC248/WG 37 and ISO/TC38/WG 34**

Further method development was conducted within the CIA- initiative with the goal of submitting a proposal to CEN/ISO for assessing microfibre release from synthetic textiles during washing.

The first meeting took place on the 25th of April 2018 and up to the 31st of December 13 technical meetings have been held. During this period, three round robin trials were performed. Both fabrics and filters were investigated. A proposal was submitted to CEN during autumn 2020. ISO and CEN are cooperating regarding this method. RISE has an expert representing Sweden in both working groups; CEN/TC248/WG 37 and ISO/TC38/WG 34 “Microplastics from textile sources”.

From March 2022, the standard “ISO/DIS 4484-1: Textiles and textile products — Microplastics from textile sources — Part 1: Determination of material loss from fabrics during washing” is available as a working document at ISO [19].

Next step in the standardisation process, is that the final working document needs to be registered for formal approval. The final approval is expected to take place during 2022.
6. FABRIC CONSTRUCTION - EXPERIMENTAL

The work within the experimental trials that were carried out included various aspects, as investigating different materials and validation of results. Fabrics that were tested in the project were collected from partners in the project. To be able to collect relevant fabrics in the project, The University of Borås created a template for all partners that provided the project with samples to fill in, see APPENDIX - MinShed template.

However, it turned out to be a more complicated task to collect relevant fabrics than anticipated. To get relevant information about the fabrics, the template included questions involving how the fabric was produced from fibre level to ready-made fabric. Comprehensive information of fibre type, yarn construction, spinning techniques, texturizing, fabric construction and any finishing steps used in the process was necessary to get knowledge about. Early in this process, it became very clear that all this type of information was often difficult or even impossible for the brands to obtain. Therefore, the number of fabrics to test decreased significantly as only the fabrics for which there was enough information could be used in the project. It was also proved difficult to find materials that were identical except for the parameter of interest.

The selected ones were 100% polyester and dark enough to get the contrast needed against the white background of the filter for the microscopy analysis. The materials were then divided into three categories: Fleeces (brushed knits), weaves and knits (non-brushed knits). The materials were all fabrics of running meters, except for one fabric that was a ready-made garment.

Fabric rectangles of 270 x 130 mm was cut using a die cutting press. The long side parallel to the selvage. On the edges a 5mm seam was welded, then folded over twice and top-stitched in place. To secure the ends of the threads these were knotted together. Back-tacking was not used as this could cause tears in the fabric. The welded seam also flattens thick fabrics (e.g., fleece), which reduce bulk at the sample edges.

The samples were prepared from the different test materials, with three replicas each. They were conditioned and weighed before and after each wash cycle, including rinse cycle.

The rinse cycle was executed in the same manner as the main wash, see conditions in Table 4. After the wash cycle the fabric sample and ball bearings were separated from the wash liquid. The fabric samples were squeezed to remove excess liquid, dried and then conditioned for weighing. The liquid was bottled and kept for filtration.

*Table 4 Washing conditions*

<table>
<thead>
<tr>
<th>Distilled water</th>
<th>Temperature</th>
<th>Time</th>
<th>No. of steel ball bearings</th>
</tr>
</thead>
<tbody>
<tr>
<td>360ml</td>
<td>40°C</td>
<td>60 minutes</td>
<td>50</td>
</tr>
</tbody>
</table>
The liquid from the main wash was later sampled and filtered for analysis. Due to problems to quantify the fibres if they were too many on the filters, only 5% of the wash liquid was filtered. Before filtering, all the liquid was thoroughly mixed to make sure the distribution in the liquid and on the filter was even. 90 mm DVPP membrane filters with a pore size of 0.65µm was used.

The result from the microscopic analysis was recorded as numbers of particles and fibres respectively. The size range of detected microfibres was approximately 5 µm up to 5 000 µm (counted fragments below 5 µm is only indicative and were not included in the result). Manual analysis for size range 200- >5 000 µm, automatic counting in light microscopy for 1-99 µm. Due to the number of particles on each filter it is not feasible to perform manual analysis for the smaller size particles.

**Thesis - Critical review on traceability of used material in current research**

Referring to the experienced difficulties of obtaining valid info about fabrics a critical review was made focusing on investigating the traceability of fabrics in published literature. This is a short summary of the bachelor thesis “Microplastics emissions during domestic laundering – a critical review of current research on microplastics emissions during washing [20].

Figure 4 show the selection process starting with 52 articles selected within in the textile area evaluating microplastics emissions during washing. Additional information regarding the fabrics used in the studies was investigated. This includes information of yarn, material, construction and treatments. Out of 18 research studies, five articles went on to the last step. The articles were called G, I, L, M and O as short name. In the end there were only two research articles left with full transparency regarding the used material samples.

![](image.png)

*Figure 4 Flowchart of the selection of articles using transparency as parameter*

The conclusion from the critical review is that the lack of transparency is an obstacle for companies to prioritize better design choices and to perform adequate research. It is very hard to draw any valid conclusions if more than one parameter differs at a time when evaluating microplastic emissions. It is vital for further research to get full...
information. It is recommended to produce fabrics in the company’s own factory, if possible, to get full transparency.

Another way would be to have a full transparent exchange of information with the manufacturer to have full control over the different processes.

Results and discussion

In 2017, Sandra Roos et al. [21] investigated possible causes of fibre fragmentation as a part of the Mistra Future Fashion cross-disciplinary research program. An experimental evaluation of whether the fibre fragmentation from different types of polyester fabric is dependent on construction parameters or not was performed. The preliminary findings showed that fibre fragmentation can be mitigated with less brushing and if ultrasound cutting is used instead of scissors. Fleece is often told to be one of the worst fabrics when it comes to high amounts of fibre fragmentation. However, results from the MinShed project indicated, depending on choice of finishing steps in the production, that fleece is not automatically worse than weaves.

Christina Jönsson et.al 2018 [16] published an article where a method for testing fibre fragmentation was presented. This method was then used to verify the findings in S. Roos et al. report (This method is also the base of the method that are evaluated and used in this MinShed project). The results in the study indicated that using ultrasonic instead of scissors when cutting the edges of the fabric can decrease fibre fragmentation by up to a third. Using some from these two studies, the MinShed project continued to investigate whether using ultrasonic welder was better than conventional cutting. Even though the method has been slightly changed during the method development, the result of the tests performed within the MinShed project show the same result - ultrasonic is better than conventional cutting.

Other results from tests within the MinShed project also show that choice of mechanical finishing steps and cutting technique do most likely affect the fibre fragmentation at different levels. Due to the lack of an aligned method, the results could not be compared with other studies, therefore it is impossible to know exact which parameter that has the most impact. Samples of a fabric from different production steps showed that a clear majority of the microplastics came from the manufacturing processes compared to the ready-made fabric. In this study the fibre release from all production stages were in total 1 713 mg/kg compared to the 80 mg/kg from the ready-made fabric, see Table 5. In this case the production steps represent 95 % of the total emissions after one wash. This indicates that the production can have a large impact.

Table 5 Fibre release from different production steps after one simulated wash cycle. The values are mean values from three replicas.

<table>
<thead>
<tr>
<th>100 % recycled polyester</th>
<th>Fibre release (%), mean value</th>
<th>Fibre release (mg/kg), mean value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step</td>
<td>Value</td>
<td>Unit</td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>Circular knitted gray fabric</td>
<td>0.10</td>
<td>988</td>
</tr>
<tr>
<td>After dyeing and cutting pile</td>
<td>0.05</td>
<td>516</td>
</tr>
<tr>
<td>After brushing the pile</td>
<td>0.06</td>
<td>638</td>
</tr>
<tr>
<td>Last finishing stage</td>
<td>0.015</td>
<td>146</td>
</tr>
<tr>
<td>Washed and finished fabric</td>
<td>0.01</td>
<td>80</td>
</tr>
</tbody>
</table>

One often discussed topic is whether recycled PES is worse regarding fibre fragmentation than virgin PES. One study compared recycled PES to virgin PES regarding fibre fragmentation [22]. The findings in that study showed that 70% recycled polyester shed significantly fewer microfibres than the 40% recycled polyester. Due to lack of information about which recycling technology that have been used in different studies, there are still many research gaps. In mechanical recycling, the fibres are separated by tearing, and the fibre length will probably be affected negative by the mechanical process. I.e., the material that are put into the process is the same as what comes out. In the case of thermal recycling, similar scenario applies; the fibres are re-melted, but the material is still the same, with the same amount of dirt and additives before and after recycling. This means that the quality of the PES itself cannot be improved after this kind of processes. However, in the case of chemical recycling, the polymer chains are broken down into its monomers, pigment and other residues are removed, then the monomers are polymerised into a new PES fibre again. In theory, using this process, unless all other steps are the same, a chemically recycled fibre will have the same quality as a virgin fibre.

In another study [21], where new PES and chemically recycled PES were compared, there were no significant difference in the amounts of microplastics emissions between the materials, which mean that in this case, recycled PES is not worse than virgin PES.

In the MinShed project a smaller investigation was made, where recycled versus virgin polyester in clothing labels was compared. Figure 5 show that the virgin material loses more weight in both the rinse and wash cycle, than the recycled. It also shows that the weight loss for both materials is reduced in the main wash as compared to the rinse cycle.
The virgin material shed more particles detected as fibre shaped, however the recycled material shed more particles overall, see Figure 6. Figure 6 also shows the size distribution where the recycled material shed slightly less of the larger particles (over 200µm). A non-fibre shaped particle can still have the same material origin as the fibre shaped ones, most of them appear to be from the test material.
The result from the gravimetric analysis shows the largest mass reduction from the virgin material, whereas the microscopy showed the largest numbers of released particles/fibres from the recycled material. To date there are no guidelines on how to interpret such a result. What is most important, low weight loss or a low number of particle release? Large particles, fibre shaped or not, can be fragmented into many smaller ones. On the other hand, the smaller the fragments the more difficult they are to capture even at WWTPs. In this case it was decided to regard the weight as most important since the difference of the number of released particles from recycled and virgin material <200 µm was only 289, in favour of the recycled material. The result also shows that one cannot get the whole picture by just gravimetric analysis.

The lack of transparency is a problem when testing commercial fabrics from different brands for evaluating microplastics emissions. Transparency is vital to be able to make the right decisions and recommendations.

Further research regarding finishing treatments and construction parameters (for example twist and spinning techniques of yarns), is pursued within the EU project HEREWEAR, where RISE is responsible for the environmental and microplastics analyses. In HEREWEAR the fibres, yarns and fabrics are produced within the consortium with full transparency.
7. HEALTH IMPACTS OF MICROPLASTICS

Washing of textiles is suggested as one of the major sources of microplastic in aquatic environments, and within the textile industry the use of chemicals is extensive. It is assumed that microplastics attract various hydrophobic pollutants in natural environments. It has been stated that several aquatic organisms ingest the small particles, but the biological effects are not yet well studied. Two summarized studies are included in this report, one thesis regarding toxicity of chemicals associated with microplastic fibres and one comprehensive study focusing on microplastics as vector for DWR (Durable Water Repellent) chemicals.

**Thesis - Microplastic polyester fibre as a source and vector of toxic substances: Risk assessment and evaluation of toxicity**

This thesis by Maria Eriksson Andin investigates toxicity of a selection of textile additives and environmental pollutants that have been observed to sorb onto microplastics [23]. The thesis was conducted in cooperation with The University of Gothenburg.

Chemicals associated with textiles were selected for further evaluation.

*Table 6 Selected pollutants and additives. Pollutants found to sorb onto microplastic PET (Polyethylene terephthalate), LDPE (Low Density Polyethylene) and UHMWDPE (Ultra High Molecular Weight Polyethylene).*

<table>
<thead>
<tr>
<th>Sorbed pollutants</th>
<th>Brominated flame retardants (PBDE)</th>
<th>Perfluorinated alkylated substances (PFAS)</th>
<th>Phthalates</th>
<th>Metals</th>
</tr>
</thead>
<tbody>
<tr>
<td>BDE-99</td>
<td>PFOA</td>
<td>DEHP</td>
<td>Al, Cr, Mg, Fe, Co, Ni, Zn, Cd, Pb</td>
<td></td>
</tr>
<tr>
<td>BDE-209, Tetrabrom phthalimide, DBDPE</td>
<td>PFOA, PFHxA, PFNA, PFBA, PFDA, PFHxS, PFOS</td>
<td>DEHP, DIMP</td>
<td>Zn, Cd</td>
<td></td>
</tr>
</tbody>
</table>

For some specific species the toxicity was, in decreasing order: PFDA > PFNA > PFOS > PFOA > PFHxA and DIMP > DEHP. This suggest several textile additives to be more toxic to aquatic species compared to sorbed pollutants. In addition, calculations of human exposure to PFOA, PFOS, DEHP and DIMP via consumption of fish were carried out. Under the assumption that fish only are exposed to chemicals via ingested microplastics, the calculations show that there is no risk to humans to exceed Tolerable Daily Intake level (TDI) of the investigated chemicals. Microplastics can also be found to a large extent in textile mills. Therefore, textile workers can indirectly be exposed to textile chemicals via inhalation of microplastics. However, calculations in the
thesis indicated that microplastics will probably not contribute unhealthy concentrations for the two investigated phthalates, DEHP and DINP.

Since this research field is rather new and associated with a lot of uncertainties, more research is required to confirm these findings and further assess chemical risks regarding microplastic fibres.

**Article - Release of Side-Chain Fluorinated Polymer-Containing Microplastic Fibres from Functional Textiles During Washing and First Estimates of Perfluoroalkyl Acid Emissions**

An interesting study that was followed closely by the MinShed project is a study focusing on investigating microplastics and their ability to act as a vector for DWR chemicals, by Steffen Schellenberger. Below is a summary from the published article[24].

The quantity and composition of fibres released from functional textiles during accelerated washing were investigated using the Gyrowash method. Two fabrics, polyamide (PA) and polyester/cotton (PES/CO), were selected and coated with perfluorohexane-based side-chain fluorinated polymers. Fibres released during washing ranged from ~10 to 500 μm with a similar size distribution for the two textile types. The PA-based fabric released considerably more fibres >20 μm in length compared to the PES/CO-based fabric. After one Gyrowash (which corresponds to 2−15 domestic washes), fibres that contained approximately 240 and 1300 μg total fluorine per square meter were released from the PA and PES/CO fabrics, respectively.

![Figure 7 Schematic picture showing the release of PFAA-precursors linked to fibre surface](image)

Current understanding of the fate of microplastic fibres suggests that a large fraction of these fibres reach the environment either in effluent wastewater or sewage sludge applied to land. In the environment, the fluorinated side chains will be slowly cleaved
from the backbone of the side-chain fluorinated polymers coated on the fibres and then transformed into short-chain perfluoroalkyl acids.

On the European scale, emissions of up to \( \sim 0.7 \) t of fluorotelomer alcohol (6:2 FTOH) per year were estimated for outdoor rain jackets treated with fluorotelomer based side-chain fluorinated polymers. These are low emissions estimates in comparison to global emissions estimate for PFAAs released during the life cycle of consumer products.
8. FILTER SOLUTIONS FOR WASHING MACHINES

This part of the project aimed to study technical solutions for capturing released micro-sized particles during consumer washing. As the research project MinShed and the Swedish Environmental Protection Agency were interested in the same filter study this study was conducted in cooperation with the Swedish EPA and RISE during 2018 [25]. This chapter is a condensed version of the study.

Objective

The overall objective of the study was to evaluate if existing filters for washing machines have a potential to mitigate microplastic pollution from textiles by decreasing the amounts of microplastics in the laundry effluent that is released to the wastewater. The study has two parts: one literature survey and one laboratory study.

Limitations

To show the full potential and limitations of filters for washing machines would require a very comprehensive study. In this case the aim of the study is not to investigate the washing machine, the fabric or the detergent, but to make a first evaluation of the potential to reduce the release of microfibres that reaches the waste water treatment plant if installing a filter to a domestic washing machine. Therefore, the influencing parameters has been set to a minimum. This study does not include detergent, ballast or any life length estimations of the different filters. No tests regarding removal of stains have been included in the study.

Literature survey and market research

Since the technological readiness of filters is important in this overview, we chose to include only initiatives where we could find a description of a proposed filter. Other initiatives that that had a low technological readiness level was not included. Also, there were no integrated solutions (where the filter is located inside the washing machine) available. Two of the manufactures that were contacted pointed out the need for legislation. Other manufacturers mentioned the need for more knowledge and more research before it can be decided where the mitigation measures will have the best effect.
Filter solutions

After reviewing the market, three different commercially available filter solutions were chosen to be included in the study. These were:

**Planet Care**
External filter connected to the outlet hose with a replaceable cartridge. When the cartridge is full it is returned to the manufacturer and replaced with a new one, as a subscription service.

**Filtrol 160™**
External filter connected to the outlet hose and attached to the wall. The filter bag inside the holder captures the microplastics and the content is manually discharged by the consumer.

**GuppyFriend washing bag**
A zipped bag which is inserted inside the drum of the washing machine where the consumer is to put clothes inside the bag and then manually clean the bag after washing.
Experimental set-up

Five different set-ups were tested:

- A blank with just inlet tap water
- Reference fleece fabric with no filter
- Reference fleece fabric with a “PlanetCare external filter”
- Reference fleece fabric with a “Guppyfriend washing bag”
- Reference fleece fabric with a “Filtrol 160™ external filter”

The results from the different filter were anonymized and results were displayed randomly given the names B, C and D. The reference fleece fabric tested with no filter is called A in the results.

The reference fabric (Figure 11) is a 100% polyester two-sided brushed virgin fleece, (article KW-3028A) and was provided from the company Kingwhale in Taiwan. Samples of approximately 300 grams were cut out and overlocked. Total load was 2 kg. Since the aim in this study was to test the filters and not the fabric, there were no need to close the edges with an ultrasonic sound equipment to prevent extra shedding.

![Figure 11 The reference fleece fabric](image)

The washing trials were performed four times for each washing set-up with the same reference sample in a previously unused new Electrolux W555H, programme 40°C mild wash. After each washing cycle the reference fleece fabric was line dried at ambient temperature (approximately 20 °C) in the laboratory. During each wash cycle the outlet water was collected in a barrel from which a water sample of approximately 500 ml was collected and a representative sample was filtered.

The fleece fabric and the filters were weighed (conditioned at 20°C and 65% RH) before and after the four wash cycles and the fibre loss and fibre retention was calculated. The fleece fabrics and the filters were not further analysed. The filter used in this study was Durapore® Membrane Filter, 0.65 µm (DVPP04700).
After drying the membrane filters, the particles were counted automatically in a light microscope (Equipment: Leica DM4000M microscope. Software: Leica Cleanliness Expert V. 4.9). The microscope analysis identified the quantity of fibre shaped and non-fibre shaped particles in different size classes. The parameters used for fibre detection was a fibre length-width ratio of 10:1. Additional manual analysis of particles was conducted of the 100 largest non-fibre shaped particles as well the largest fibre shaped particles and for fibre shaped particles larger than 500 µm.

Results from the washing trials

The result from the microscopic counting indicates that filters can catch a fairly large number of particles, see Figure 12 and Figure 13.

![Figure 12](image)

*Figure 12 The results from the microscopic particle counting shows the numbers of particles (x-axis) and their size-fractions in the outlet water from the washing trials. A1 to A4 is the amount of fibre shaped particles and non-fibre shaped particles in total after washing cycles 1 to 4 when no filter was used. B1-4, C1-4 and D1-4 are results from the trials with the three different filters.*

The first washing cycle is releasing much more particles, fibre shaped and non-fibre shaped, than the following three washing cycles. Set-up A “fabric with no filter” releases more than three times as many particles (regardless of shape) in total after the first washing cycle than any of the filters do taking into account all four washing cycles. This indicates that there are a lot of loose particles (fibre shaped and non-fibre shaped) from the manufacturing process and perhaps also other sources than the fabric itself. All four set-ups (with and without filter) show a decline regarding particle content (both fibre shaped and non-fibre shaped) from washing cycle 1 to 4. This overall reduction of shed particles is possibly due to less shedding from the fabric.

Fibre shaped particles (i.e., particles with a fibre length-width ratio larger than 10:1) were also assessed separately and the results show that the number of particles in the outlet water that are defined as fibre shaped are rather few, see Figure 13. As an example, the total number of particles in A1 was ~8000, see Figure 12 and of these only ~375 were fibre shaped, see Figure 13, according to the fibre definition used in these
calculations.
Note that this does not mean that the particles are from any other origin than the fleece material. They just have a smaller length-width ratio than the decided definition of “fibre shaped”.

![Fiber shaped particles](image)

Figure 13 The results from the microscopic particle counting shows the numbers of fibre shaped particles (x-axis) and their size-fractions in the outlet water from the washing trials. A1 to A4 are the number of fibre shaped particles in the outlet water fibre after washing cycles 1 through 4 when no filter was used. B1-4, C1-4 and D1-4 are results from the trials with the three different filters. Since the lower limit for analysis is 5 µm and since the fibre length-width ratio is 10:1, no particles smaller than 50 µm can be defined as fibres in these calculations.

The result from the weighing indicates that the filters catch particles from approximately 30 weight percent up to 60 weight percent in this study (Table 1). One should keep in mind that these are very small differences and weights. Weighing can also include different contaminations, even though for example the detergent was excluded. I.e., the results from the weighing in this study should not be used to compare the filters. Therefore, general conclusions are shown in Table 1 instead of reporting results for each filter.
Table 1  Weight loss and retained particles after 4 washing cycles

<table>
<thead>
<tr>
<th></th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate weight loss of the fleece fabrics after 4 washings</td>
<td>0.7-1.2 g</td>
</tr>
<tr>
<td>Approximate weight loss of the fleece fabrics after 4 washings</td>
<td>0.2-0.4 %</td>
</tr>
<tr>
<td>Approximate retention of particles in the filters</td>
<td>30-60 %</td>
</tr>
</tbody>
</table>

Note: During 2020 RISE led an innovation contest addressing filter solutions for domestic washing machines. From the results one can conclude that the top filter solutions had a higher retention rate (up to 80%) than the best one from 2018.

Discussion

When considering if a filtering solution should be absolute (i.e., removing 100 % of the microplastic fibre shed from the textiles during washing) one also need to consider what other consequences this may have for environmental and economic sustainability of washing textiles as well as practical aspects such as user friendliness. Note that none of the producers of filters suggested for usage with washing machines claim to remove all microplastic fibres shed from the washed textiles.

The removal of major weight fractions of the plastic fibres has a potential to mitigate microplastic pollution, even if not all fibres are of microplastic size. The experimental trial showed that filters could decrease the numbers of particles in the whole size-range of 5-1000 µm that was studied.

The result from the washing trials shows that microplastic shedding is most severe during the first washing cycle. These fibres could potentially be removed by using filters at the textile production facility. However, since filters can decrease the release of microplastics also during the 2nd, 3rd and 4th washing cycles, the use of filters for washing machines is still a way to prevent microplastic release from many future washing cycles.

There are some practical issues to consider when using a washing machine filter. It is necessary to address a potential increased energy consumption when concluding of the economic and environmental sustainability of a filter. There would have to be a trade-off between having a finer filter that traps more microplastics and having a less fine filter that consumes less energy.

When addressing all users of washing machines there are additional concerns that need to be considered. Installing, replacing and emptying the filters was found to be easily done during the washing trials. The operations did however take some effort. To change or empty a washing machine filter could be a discomfort to some users, and a reason for them to omit buying a machine with a filter and if they already have such a machine, a reason to neglect cleaning or replacing it. Therefore, legislation that obligates the usage
of filters may be necessary to make it economically sustainable for a washing machine producer to include filters in their appliances. For the same reason it is important that the filter cannot be removed or by-passed by the user, and it is obviously preferable that filter maintenance is as simple, quick and clean as possible.

Conclusions

The washing trials support that different filter can remove a fairly large part of the microplastics from the water. To elucidate exactly how efficient those filters are at removing microplastic emissions would require more comprehensive laboratory work.

There are some questions which may influence choices of technologies and legislation for filtering solutions for domestic washing machines, and which may need further attention.

- What are the total positive and negative environmental impacts (e.g., more material use, adequate recycling systems, increased energy consumption) of filtering solutions for washing machines?
- How efficient do the filters need to be to have a positive impact on the environment?
- How can the filtering solutions be designed to be more user-friendly and to make the maintenance as simple as possible?


This master thesis was performed 2018-2019 by Lorenzo Del Frari at the University Udine in Italy and Electrolux Professional. The part of the thesis that is not confidential was presented at a MinShed partner meeting in May 2019 [26]. Although detergent is out of scope it was still regarded as interesting for the MinShed consortium. This this is a summary of the presentation.

Experimental set-up

Washing machine: Electrolux W565H
Wash cycle: Approx. 60 minutes
Rinsing: Reduced to ca. 3% of normal rinsing
Temperature: 20°C and 90°C
Powder detergent: Standard detergent according IEC 60 456 with zeolites, dosage 24.3 g/kg
Liquid detergent: Electrolux Lagoon® Delicate, 8 ml/kg
Material: 100% polyester two-sided brushed virgin fleece, (article KW-3028A) (note: same as MinShed)
Ballast: Shower curtains (100% polyester)
Total load: 3.25 kg (half load)
Filtration: Membrane filter (5 µm)
The trial was conducted with consecutive washing cycles, i.e. without any drying between the cycles. The rinsing was reduced to 3% compared to normal level. As reference, consecutive wash cycles with just water at 20°C and 90°C were used. The result show that there can be significant clogging problems with filters, especially with high dosage of powder detergent including zeolites, see Figure 14. Hence, it was decided to use a liquid detergent instead.

![Figure 14 Zeolites including residues from a single wash collect in the filter.](image)

Three distinct residues were analysed with optical microscopy and SEM. The chemical composition was detected to consisted of a mix of fibre fragments in different shapes, limestone scale and detergent scale. No analysis had been made at the time of the presentation regarding the quantitative interrelation between the different substances.

![Figure 15 Deposit mass per filtered water- summed up](image)

In this accelerated trial it is evident that detergent has a large impact at both 20°C and 90°C. Another interesting result is that temperature only seems to have an impact
when detergent is included. This set-up includes consecutive washing cycles with “no” rinsing to enhance the chemical impact of the test material. Hence, these results cannot be compared to trials including both rinsing and drying, as in the other wash studies included in MinShed or Textile Mission [27]. With hardly any rinsing in the wash cycle and no drying between the washing cycles, the increasing amount of residues derive from detergent scale and limescale scale as well as fibre fragments accumulating with the number of washing cycles.

Further research includes investigating more interrelations. Although impact of detergent is out of scope in the MinShed project, optimizing detergent for minimizing microplastics release is an interesting question.

Mitigation of microplastics emissions at production facilities

During 2021 RISE have been part of TMC’s Wastewater Task Group looking into mitigating measurements at textile production facilities. The conclusion is that an adjacent wastewater treatment at the textile production facility is a way to significantly reduce the microplastic emissions.

To reach as high retention rate as possible, MBR (membrane bio reactors) and UF (ultrafiltration) is recommended separately or in combination. Note that UF / MBR filter will provide added benefits as well, like retention of other solids. Within these techniques it is also possible to divert the microparticles, regardless of origin, into the
sludge using crossflow or dead-end UF modules.

Note that an investment should be seen as a commitment to reduce the overall impact and not solely for mitigating microplastics emissions. Up-stream wastewater treatment is also applicable at, for example industrial laundries.

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**Figure 17** Schematic showing filtration with consecutively smaller filtration techniques. In a textile mill, the raw water could be the wastewater leaving the dyeing equipment, whereas the ultrafiltered water can be discharged or reused in the facility again. Graphic courtesy of [http://crystalquest.com/pages/what-is-ultrafiltration](http://crystalquest.com/pages/what-is-ultrafiltration).

**Future policies and legislation on EU-level**

EU is looking into possible policies and measures for mitigation of microplastics from different sources, where washing of synthetic textiles is one defined source. Two stakeholder workshops concerning “Cost-benefit analysis of policy measures reducing unintentional releases of microplastics” and the “Call for evidence for an impact assessment” have been organized where RISE participated and where results and findings from the MinShed project was shared.

Emission estimates have been made, see Figure 18. The emissions are categorized and the data quality is evaluated from poor, medium to high. [28]
From workshops with stakeholders the EU project team is now investigating cost and benefits with several possible approaches, for example:

- restrictions of synthetic fibres for certain applications
- restriction of fibre and fabric with high emissions
- emission limit during production
- specific wastewater treatment in production plants
- mandatory washing before placing on the market
- making filter compulsory for washing machines
- communication campaign aiming at raising awareness and communicating best practise for consumers
- create a standardized measure to quantify microplastics emissions on the lifecycle

The last example being mandatory for other measures.

France has already decided that from 2025 there is to be a mandatory filter in all new manufactured washing machines commercially available in France.

As up to now (March 2022) there is still no standardized method for assessing filter solutions for washing machines and no limit for acceptance. The washing trials within the MinShed project on filter solutions can serve as a first basis for a standard development and RISE is looking forward to contributing to this work.
9. WASHING TRIALS – IMPACT OF WASHING PARAMETERS

Many published articles [29, 30] focus on occurrence in the recipients or microplastics emissions from a material perspective. Apart from the fabric itself there is an ongoing discussion about the impact of the washing process. Also, the impact of detergent has been up for discussion. However, investigation of detergent relative to microplastic emission (i.e., the fibre fragments from the synthetic fleece test sample) is considered out of scope in this project. It was chosen to use a commercial liquid detergent since the literature suggests that powder detergents may increase the microplastics emissions.

The function of a domestic washing machine is to refresh and clean textiles and at the same time cause minimal damage to the textiles. But exposing textiles to elevated temperatures as well as mechanical action and chemicals (detergent) will most likely have some impact. Therefore, it is of interest to investigate the amplitude of this impact and if any of the parameters stand out in terms of contributing to microplastic emissions.

It is known that several parameters are also co-dependent: the type of soiling, degree of soiling, fibre material etc. This study looks closer at three parameters that is defined by the MinShed consortium to possibly have a negative impact on microplastics emissions from the washing machine point of view. To address this knowledge gap, it was decided to conduct an initial test series with focus on three parameters: temperature, washing time and water level.

Aim

The goal of this study is to investigate how microplastic emissions during washing is affected by the temperature, washing time and water level during the washing process.

Experimental

Table 7 Experimental set-up

<table>
<thead>
<tr>
<th></th>
<th>Electrolux W555H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washing machine</td>
<td></td>
</tr>
<tr>
<td>Wash load</td>
<td>- In total 3 kg</td>
</tr>
<tr>
<td></td>
<td>- ballast: 2,4 kg white polyester standard ballast</td>
</tr>
<tr>
<td></td>
<td>- test material: 2 pieces á 300 gr black fleece with overlocked edges</td>
</tr>
<tr>
<td>Detergent</td>
<td>20 ml of liquid detergent “Via Color Sensitive” batch no. 91571</td>
</tr>
<tr>
<td>Number of washes</td>
<td>5 per set</td>
</tr>
<tr>
<td>Drying of sample</td>
<td>hang-dried in ambient temperature</td>
</tr>
</tbody>
</table>
Filtering
- Effluent water sample: 3 litres
- Pore size of filter: 10 µm (nylon net filter)

Scale
- Mettler Toledo, AT 200, accurate down to 0.0001 g in standard climate

Drying of ballast
- Tumble dryer: Electrolux T5130-LAB
- Temperature: maximum 80 °C
- Time: 45 minutes

The effluent from the washing process was collected in a barrel from where 3 litres were extracted. To get a representative sample the effluent liquid was stirred for 30 seconds with a large stirrer. After filtering, the filtrate was conditioned in a laboratory (20°C, 65% RH) to constant weight and analysed gravimetrically.

To be able to vary the three parameters as wanted the washing machine was programmed with a number of customized washing programs specific for this study, see Table 8. The two temperatures, 20°C and 60°C, were chosen to get a larger temperature difference than using the most common washing temperature for synthetic fibres - which is 40°C. The washing time in the main wash was set to 10 minutes or 60 minutes.

<table>
<thead>
<tr>
<th>Washing process</th>
<th>Temperature [°C]</th>
<th>Time at main wash [minutes]</th>
<th>Approximate water use [litre]</th>
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<td>10</td>
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</tr>
<tr>
<td>60.60.EW</td>
<td>60</td>
<td>60</td>
<td>57</td>
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</tbody>
</table>

The only difference with 20 °C and 60 °C with duration of 10 minutes and 60 minutes respectively is the time during the main wash. All other parameters, as for example number of rinses, was kept the same. Two set-ups for “extra water” were included for the two programs 20 °C/10 minutes and 60 °C/60 minutes.

The washing machine was rinsed three times between the different set-ups to prevent cross contamination. The rinsing was validated through filtering and analysing the wastewater filtrate.

It is well known at textile laboratories that filling the washing machine with half load is more severe to the textile than a full load. The reason is that the textiles get a higher drop height and thus higher mechanical impact. With half a load the liquor ratio is larger.
which means that textile will have more water flowing in and out, hence easier for the microplastic fragments to be detached from the textile. For the reasons described above, a total load of 3 kg was chosen (whereas a full load would be 6 kg according to the manufacturer).

Results

The results from the washing trials show that for both 20 °C and 60 °C water level stands out the most, see Figure 19, Figure 20 and Figure 21. In Figure 19 the medium blue line for 20 °C/10 minutes + extra water after one wash (0,45 g/kg) is significantly above the light blue line representing 20°C/10 minutes (0,28 g/kg). A similar result was obtained for 60 °C/60 minutes + extra water (orange) compared to 60 °C/60 minutes (brown line), though the difference was smaller 0,37 g/kg versus 0,25 g/kg.

The duration of the wash program also seems to have a small but noticeable impact. For both 20 °C and 60°C the longer wash program with a duration of 60 minutes sheds more than the 10 minutes wash. There is one inconsistent result for 20 °C after one wash, which is probably due to using only one replica. However, the overall trend is by using a longer program the emission increases, see Figure 20. This result also aligns with the result from the research project Textile Mission [27], “the choice of wash program can have a slight influence on the fibre output”. (Note: Two programs were used in Textile Mission. An Easy-Care program with a duration of 1,59 hours and an Express program with a duration of 30 minutes.) All washing programs adds mechanical action and friction to the textile. Consequently, one can also use this fact to predict that long duration programs also will increase microplastic emissions as result of the prolonged mechanical stress.

The largest quantity of shedding occurs after the first wash, as anticipated, and then
declines with the number washes. This study only included five washes. I.e., the study does not include any investigation if and when the reduction might end and the emission increases again. The project Textile Mission [27] washed up to 10 washes with a number of different textiles with no evidence of increase in microplastics emissions. Washing series up to 20 or 30 cycles is probably required to investigate this further.

After one wash at 20°C, there is no difference, but after three washes the green line representing 60 minutes show higher emissions the light blue line representing 10 minutes. However, the two lines are almost colliding again after five washes. This could indicate that the reduction after five washes is reaching its lowest rate with this set-up. The comparison 60°C - 10 minutes and 60 minutes looks a little different. From having just a little more emission at 60 minutes after the first wash the two lines (orange and brown), are parallel with the 60 minutes line clearly above the 10 minutes line. In Figure 20 and Figure 21 the results are also shown separately as staple bars from 20°C and 60°C.

![Graph showing released fibres from wastewater in mg/kg of washed fabric. Separate comparison at 20°C.](image-url)
After the first test series there was a discussion concerning the impact of the tumble dryer, especially of the amount of collected fibres in the following washes.

During the testing it was noticed that a lot of black fibres were collected in the lint filter of the tumble dryer when tumble drying the white ballast. This shows that some of the fibre fragments from the test sample got stuck on the ballast. Therefore, an extra set of tests were performed to further investigate and if possible, quantify these fibres. The set-up 20 °C/10 minutes was chosen for the extra tumble dry test, see Table 9.

**Table 9 Additional test with tumble dried sample from 20°C / 10 minutes**

<table>
<thead>
<tr>
<th>Washing process</th>
<th>Temperature [°C]</th>
<th>Time at main wash [minutes]</th>
<th>Collecting tumble dryer lint before first wash [mg/kg]</th>
<th>Collecting tumble dryer lint after first wash and forward [mg/kg]</th>
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<tbody>
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<td>20.10</td>
<td>20</td>
<td>10</td>
<td>X</td>
<td>-</td>
</tr>
</tbody>
</table>
As can be seen in Figure 22, the quantity of fibres in the wastewater with tumble drying before the first wash versus hand-dried is not significant less than with no tumble drying (the first two staple bars at the left in Figure 22). Although there are some fibres that is not accounted for, tumble drying before the first wash does not seem to reduce the number of fragmented fibres in the effluent water from the washing machine. But if the fleece is tumble dried between the washes, this seems to significantly reduce the fibre shedding entering the wastewater. In this trial the microplastics emissions were reduced by approximately 55% (from 69.5 mg to 30.7 mg) after wash number 5.

**Conclusion and discussion**

The trials in this study were performed with one selected fleece fabric and the results should be regarded as indicative. However, there are several insights and interesting results. The research project Textile Mission [27] have come to many of the same conclusions which of course strengthen the results in this project. Textile Mission is a large research project that included a total of 23 materials which were tested in more than 850 washing cycles, but only at 40°C (whereas MinShed tested 20°C and 60°C). The load, duration of washing cycle and spinning were varied, and so was including/excluding softener. Both MinShed and Textile Mission used liquid detergent in the trials.

The largest amount of emissions occur after the first wash, regardless of time, temperature and extra high water level. The emissions decline up to wash number five which is the last wash in this study.

The microplastic fragments on a textile can originate not only from the fabric.
construction, but also from different steps from the production and potentially from cross contamination from other fabrics when shipped and stored etc. This trend is obvious in this study looking at the difference in emissions from the first wash to the third wash. Otherwise, wash 3 to 5 would not show this large reduction of emissions. The same argument is found in the report from the project Textile Mission[27], “The first two washes cover about 54 percent of the total fibre emission of 10 washes, while the 3rd to 10th wash are only responsible for 46 percent of the microplastic emission and on average show a particle emission of about 10 mg/kg in the last wash. This ratio can be observed for all constructions and finishing routes. This leads to the conclusion that the fibre fragments carried into the environment by washing are primarily residues from production.”

The finding also opens up the need of washing the samples more than one time, if the reason for testing is to evaluate for example the yarn or the construction excluding any impact from other sources. This, since the result from the first wash can be highly influenced by the manufacturing.

All three parameters, temperature, time and water level, seems to have a moderate to small impact with water level to be the most significant. Also, experience from the textile testing department at RISE is that a full load is gentler than a half a load.

Washing is probably not the largest contributor compared to manufacturing steps. However, washing is still a significant point source for microplastics entering the wastewater due to the large number of households over time repeatedly washing their clothes.

Suggested recommendations to a consumer:

- to wash with full load
- to use short wash programs
- to wash with low temperature when possible (if no requirements of disinfection)
- install a filter for the washing machine (Note that there is no standard method yet for evaluating the efficiency)

These two additional recommendations represent a “grey area”:

- not adding an extra rinse
- to tumble dry (applies to condense dryers, not air vented dryers)

Avoiding extra rinsing would reduce fibre fragments entering the wastewater, but it may not contribute so much regarding reduction of the total emission. An old rule of thumb regarding wear & tear of clothing states that 25-35% originates from the washing process, 45-55% from wearing the clothes and 5-10% from the tumble drying. I.e., the fibres that are fragmented but are still attached to the textile will fall off when wearing the clothes instead of entering the wastewater. An extra rinsing does also contribute to a higher water consumption.

Tumble drying between the washes also seem to have a positive effect, this stated solely with regard to microplastics emissions. Hang-drying causes less initial emission since a lot of the loosened fibres fragments are still attached to the textile. To some extent a tumble dryer do contribute to microplastic emissions. But most of the loosened microplastic fragments are caught in the lint filter instead of falling off wherever the
textile is used. One could argue that the net outcome of tumble drying would therefore be a reduced microplastic shedding to the environment. However, there is an argument for not using a tumble dryer for mitigation microplastics, and that is energy consumption. Just looking at energy consumption, outside hang-drying textiles is the most energy efficient option.

In this study the result from tumble drying prior to the first wash did not seem to have an impact on mitigating the microplastic emissions from the first wash. However, tumble drying after the first wash had a positive impact with less fibres entering the wastewater from the next wash. The result in this study indicates a reduction of approximately 50% after the fifth wash compared to indoor hang-drying, see Figure 22. More tests need to be conducted to see if this applies in general.

It would also be interesting to perform a long-term washing trial to see, if and when, the microplastics emissions start to increase again.

From a washing machine manufacturer point of view the largest impact for mitigating microplastics emissions will probably be to install a filter to filter the outlet wastewater. The idea of an extra filter, either external or integrated, is a hot topic. A report from the organisation Swedish Water [31] states that the retention rate for microplastics is up to 99% at the three large wastewater treatment plants (WWTP) included in their study. On the other hand, enhanced amounts of microplastics have been detected in waters nearby WWTPs [32]. Will an extra filter in household washing machines make a difference at the WWTPs considering the use of overall resources looking at both economic and environmental aspects?

Compulsory filter in washing machines is one of the measures EU is investigating [28]. Looking from another angle, implementing legislation together with a communication campaign aiming at raising awareness, can be a way to make consumers more aware and hence change consumer habits when washing and buying clothes. France has already decided to implement a legislation which makes it compulsory for all new domestic washing machines to have a filter for mitigation of microplastics.

Results from the international innovation contest “Zero Microplastics challenge 2020” led by RISE showed efficiencies up to approximately 80 weight percent in the range of approximately (10µm – 5 000µm). The aim with this contest was to accelerate the market introduction of filter solution and paving the way for criteria for microplastics emissions in the Ecodesign Directive for washing machines and filter solutions.

There is an obvious need to develop a standard method for assessing washing machine filters and decide on a limit of acceptance. This is also pointed out on EU level.
10. ASSESSMENT OF MICROPLASTICS EMISSIONS FROM LAUNDRY UNDER REAL-LIFE CONDITIONS

This chapter is a condensed version of the master thesis “Microplastic Release after Laundry of Synthetic Garments” [33]. A manuscript will be submitted to Environmental Science and Pollution Research.

Microplastic fibres release from the laundry of synthetic garments have been reported to contribute to microplastics pollution [7, 34, 35]. The emission has microplastics is typically determined with new clothes or fabrics and limited garment types. The resulting assessment of microplastics emission from laundry may therefore not represent realistic conditions. In this study, the emissions of microplastics from laundry of synthetic garments under real-life conditions, i.e., using different, worn clothes, is assessed.

Selected garments and wear

Garments
A set of new commercially available garments were obtained, including fleeces, hoodies, T-shirts, leggings, training pants and sport socks. The characteristics of the garments, including their reported composition and density, are provided in Table 2. Individual items were pooled to increase the amount of material released for each garment type and the quantity of fibres collected for each wash. For each garment type, two sets were used to assess the impact of wear: one set was not worn, while the other set was worn between washes.

Wear
Each garment from the worn set was worn for ca. 8 hours. When possible, multiple clothing layers were worn to limit potential contamination from skin particles, hair, and dust. The worn garments were shaken and wiped to remove particles that could have accumulated on the garment surface and inspected before laundry.

<table>
<thead>
<tr>
<th>Table 2 Description of selected garments.</th>
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<tbody>
<tr>
<td>Garments</td>
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</tr>
<tr>
<td>T-shirt 1</td>
</tr>
<tr>
<td>T-shirt 2</td>
</tr>
<tr>
<td>Fleece 1</td>
</tr>
<tr>
<td>Fleece 2</td>
</tr>
<tr>
<td>Hoodie</td>
</tr>
<tr>
<td>Socks</td>
</tr>
<tr>
<td>Leggings</td>
</tr>
<tr>
<td>Training pants</td>
</tr>
</tbody>
</table>
Sample collection and analysis

Laundry and sample collection
An Electrolux W575H LE professional washing machine located was at the HSB Living Lab used for the experiments. All garment sets were washed 5 times in total. Fibres were collected during the 1st, 3rd and 5th wash for each garment set. The washes were performed using the ‘eco/normal colour’ programme, which is characterised by a water temperature of 40°C and a duration of ca. 45 minutes. A detergent (Clax Elegant, Diversey) was used with auto dosage at a rate of 10 ml/kg. No softener was added during the rinse. The filters and garments were dried using the dryer Electrolux TS5140L on the mode “Extra” after each wash.

Before each wash when fibres are collected, the tumbler, inner part of the door and outflow pipe were cleaned with a brush. A pre-wash was then performed without any garment before washes when fibres were collected to remove residual fibres that may have accumulated in the machine from previous washes. Polyester filters with a 50 µm pore size (NW25, Cintropur) and filter area of 450 cm² were used to collect the fibres. The filters were washed, dried and weighed before use. Sample collection was performed by placing the filters at the outflow of the machine.

Measurement of microplastic emissions
After the wash, the filters were rinsed with 800 ml water. The garments and the filters were dried for about 80 minutes in an Electrolux TS5140LE Dryer. The dried garments and filters were kept in sealed plastic bags. The filters were then placed in a desiccator before being weighted. In addition, fibres collected on filters were taken into a deionized water solution. An Olympus BX53 optical microscope was used to measure the length and diameter of the fibres. The number of fibres released was then calculated using measured fibre dimension and fabric densities.

Analysis of garments
A piece of new, unwashed garments was cut and analysed by scanning electron microscope (SEM) using a Quanta 200 ESEM FEG (FEI) microscope with energy dispersive X-ray spectroscopy (EDAX). SEM analysis of worn and unworn garments was also performed after wash 5.

Results and discussion

Emissions rates
The released of fibres from laundry of new clothes ranged from not detected for socks to 0.20 g kg⁻¹ textile. A lower emission rate was found for all unworn garments after 5 washes, including no detectable fibres for leggings, training pants and socks. In contrast, the emission rate increased for all garments except Fleece 1 and T-shirt 2. The largest increase was found for worn socks with 1.2 g kg⁻¹ textile. It is also important to note that fibre emission was consistently higher for all worn garments compared to unworn garments after 5 washes, see Figure 23.
Observations of released fibres with an optical microscope show different patterns for the different garments. The results are however difficult to assess owing to the wide range of fibre lengths observed in each sample. For instance, fibres released from one fleece had lengths of 62-3020 µm. Diameters remained relatively consistent for all garments.

![Figure 23 Emission of fibres from the laundry of synthetic garments](image)

Scanning electron images reveal that worn garments have more damage than unworn garments with a loss of structure and cut fibres. The impact of wear is most apparent for the socks, Figure 24, which also have the largest fibre release after being worn.

![Figure 24 Scanning electron microscope images of new and worn socks](image)
Conclusions

This study shows that wearing clothes has a significant impact on the release of microplastics fibres. The emissions were consistently higher for all worn garments compared with unworn garments. The higher emission rates could be associated with damage of the textile materials resulting from wear. The results indicate that previously reported emission rates measured on unworn clothes may underestimate the emission under real-life conditions.
II. REFERENCES


3. nova-Institut GmbH, R.E., Linda Engel, Michael Carus, Dr. Ralph Heinrich Ahrens, Sources of microplastics relevant to marine protection in Germany. nova-Institut GmbH, 2015. 002147/E.


10. Bruce, N.e.a., Microfiber pollution and the apparel industry and the apparel industry. Santa Barbara, California., 2015.


12. CROSS INDUSTRY AGREEMENT - For the prevention of microplastic release in to the aquatic environment during the washing of synthetic textiles.


# 12. APPENDIX

MinShed template

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<th>FIBER</th>
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<td>Ring</td>
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<td>intermingled</td>
<td>open end</td>
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</table>

| APPEARANCE YARN | Bright | % | Semi Dull | % | Dull | % | Spindled | % | Round (Cross section) | % | Tri-lobe (Cross section) | % | Other (Cross section) | % | Low Twist (e.g. 40 rpm) | % | High Twist (e.g. 200 rpm) | % |
|-----------------|--------|---|----------|---|-----|---|---------|---|------------------------|---|------------------------|---|------------------------|---|------------------------|---|

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