TextileMission

REDUCING TEXTILE MICROPLASTICS

FINDINGS FROM AN INTERDISCIPLINARY RESEARCH PROJECT

+++ CAUSES OF MICROPLASTIC DISCHARGE
+++ RETENTION IN WASTEWATER TREATMENT PLANTS
+++ TEXTILE-TECHNICAL SOLUTION APPROACHES

www.textilemission.bsi-sport.de

IMPRESSUM

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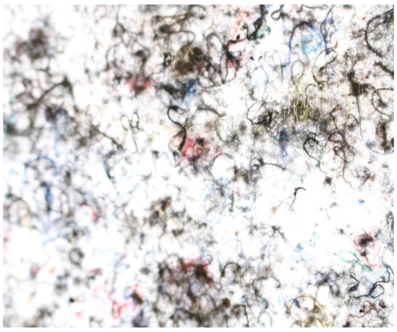

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RESEARCH PROJECT TEXTILEMISSION

GOALS, PARTNERS, RESEARCH APPROACHES

Textiles made of synthetic fibres such as polyester can emit minute fragments during production and washing. Various sportswear such as running shirts and outdoor jackets are also affected. The partners in the TextileMission research project have set themselves the task of better understanding this environmental impact and helping to minimize it. Here you will find an overview of the goals, participating organizations and central research activities.

A large proportion of our clothing, including sports and outdoor textiles, is made of synthetic materials such as polyesters. Both in production and in household laundry these garments release textile microplastics (Fig. 1), which can enter the environment via wastewater or exhaust air. When the consortium of the TextileMission project was formed in 2016, this emerging environmental problem was actually already known about by a series of international and national studies - for example by the German Environment Agency (Umweltbundesamt - UBA) and other environmental organizations.

PROJECT PARTNERS, OBJECTIVES AND RESEARCH QUESTIONS

Nine organizations from the textile research, water chemistry, environmental protection, sporting goods, household appliance and detergent industries wanted to contribute to a better understanding and a reduction of the environmental problem of textile microplastics. Their joint application for financing as part of the „Plastics in the Environment“ funding priority of the German Federal Ministry of Education and Research (BMBF) was successful.

The project partners were as follows:

- Association of the German Sporting Goods Industry (BSI)
- Hochschule Niederrhein - University of Applied Sciences - Research Institute for Textiles and Clothing,
- TU Dresden - Institute for Water Chemistry,
- VAUDE Sport GmbH & Co KG,
- WWF Germany.

The following organizations supported the project as associated partners:

- adidas AG,
- Henkel AG & Co. KG aA,
- Miele & Cie,
- Polartec LLC.

The range of partners makes it clear that the participating organizations were aware from the outset that only an interdisciplinary approach promises success that a) takes into account different stages of the production chain and the life cycle of textiles and b) works across industry and research disciplines. The project name „TextileMission“ in turn alludes to both the ecological challenge (eMission) and the desire to contribute to the solution (Mission). The challenges posed by textile microplastics and the requirements for solutions from the point of view of WWF Germany, partner can be read from page 8.

Fig. 1: Fibre fragments from a PES fleece fabric under the microscope. Photo: Hochschule Niederrhein - University of Applied Sciences

When TextileMission was launched in August 2017 the partners set the following overarching goals:

1. Gaining a better understanding of environmental issues. Questions included: What are the reasons for the loss of microplastics in textiles? What quantities are released? How can the particles be classified (e.g. according to size)?

2. Contributing to the optimization of wastewater treatment. Questions included: How are textiles microplastics re-

BMBF RESEARCH FOCUS „PLASTICS IN THE ENVIRONMENT“

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Despite the numerous activities and the amount of research in this field, our knowledge about the full extent of plastic pollution is still limited: There is still little knowledge about the origin of plastics in the ocean, inland waters and soils, or their effects on humans and the environment.

The Federal Ministry of Education and Research (BMBF) took up this problem with its research programme „Plastics in the Environment - Sources - Sinks - Solutions“. In doing so, BMBF aims to support the search for environmental resource-saving approaches, which are the focus of the of the „Green Economy“ flagship initiative that represents the core of the „Research for Sustainable Development (FONA)“ programme. Between 2017 and 2022, a total of 20 joint projects and an accompanying scientific research assignment have been and are being provided with funding of around €37 million.

Approximately €1.7 million of this budget was allocated to TextileMission. More than 100 institutions from science, industry and business are involved in what is currently the world‘s largest research focus in the field of the effects of plastics on the environment.

Futher information: www.plastik.net.

tained in a wastewater treatment plant? Which procedures could help (further) increase retention and at what cost?

3. Gaining insights into the production of lower emission textiles. Questions included: How can textile fabrics be developed that emit fewer microplastics? What reduction potential is there in finishing processes and in cutting and joining techniques? To what extent could biodegradable fibre materials contribute to solving the problem?

PROJECT SETTING: WASHING TESTS AND ANALYSIS

In order to collect meaningful data for sub-goal 1, the project partners carried out a large number of washing and drying tests with commercially available textiles. The work, which involved a great deal of time and effort, was carried out primarily in the laboratories of the Hochschule Niederrhein - University of Applied Sciences, and to some extent also at the Technical University of Dresden. The project partner Miele provided both the washing machines and its know-how on washing processes for this purpose, as did Henkel with the needed detergent and corresponding expertise. The textile samples (in particular sports outerwear made of fleece material, but also unbrushed articles) were mainly provided by the project partners VAUDE, adidas and Polartec, but also by other companies from the BSI members. The textile microplastics emitted during the washing series were captured by the researchers via special filters and their mass was determined. Based on the findings, the project partners were able to identify washing parameters and production processes that influence microplastic emissions.

It was also possible to derive tips on washing behaviour that consumers can use when washing their sportswear and outdoor clothing at home to help minimize textile microplastics. You can read more about the test results starting on page 13. More in-depth analysis of the collected particles with regard to shape, number and division into size fractions was carried out primarily by the TU Dresden.

RETENTION IN WASTEWATER TREATMENT PLANTS AND MASS BALANCE

The corresponding results flow into the research work package mentioned in sub-goal 2 (wastewater treatment). What happens to textile microplastics after they enter wastewater via household laundry? In order to learn more about the corresponding material flows, the researchers investigated the retention of textile microplastics at various stages of a laboratory wastewater treatment plant. The findings provided interesting information on the status quo of the efficiency of wastewater treatment. More information can be found in the article starting on page 19. On the basis of the findings on the amount of microplastic discharge obtained at the Hochschule Niederrhein - University of Applied Sciences and the Technical University of Dresden, a mass balance calculation was conducted that estimates the extent to which textile microplastics from sportswear are released into the environment throughout Germany (see article starting on page 24).

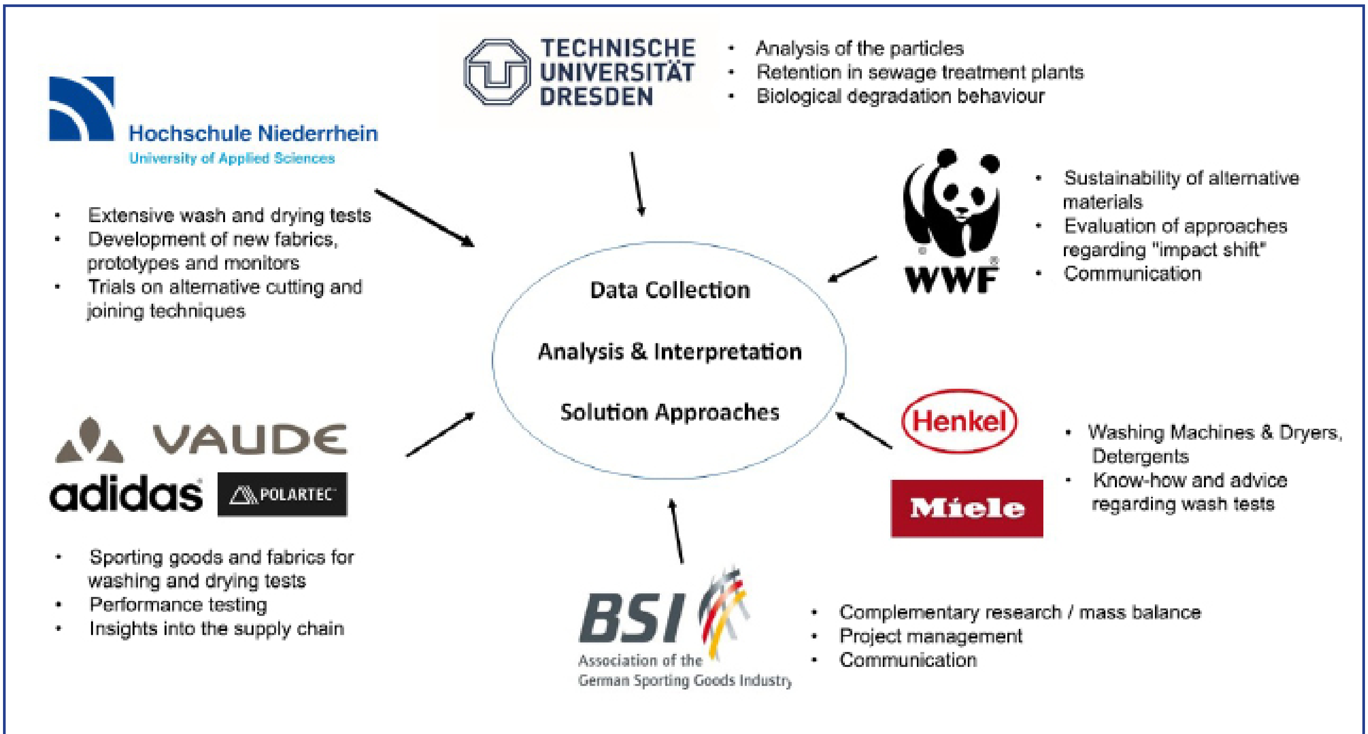

Fig. 2: As project partners nine organisations from the sporting goods industry, the household appliance and detergent industry, from research and environmental protection contributed to the TextileMission project.

Fig. 3: A presentation of the project partners’ research and quotes from the respective experts are provided by the official TextileMission video (in German). Simply click on the icon in the middle of the graphic. Graphic: FIUMU GmbH

POTENTIALS AND RISKS OF ALTERNATIVE FIBRES

Fibres made from recycled polyester and biodegradable raw materials are traded as possible sustainable alternatives to conventional polyester. In the course of the project, WWF Germany and VAUDE examined the potentials and also the ecological and social sustainability risks associated with the use of such yarns. Their recommendations on the use and selection of alternative fibres - also taking into account tests on the biodegradability of different fibre materials at the TU Dresden - can be found from page 29.

LESS MICROPLASTICS THROUGH TEXTILE RESEARCH

The findings from washing tests in particular served as a basis for textile technical experiments conducted by researchers at the Hochschule Niederrhein - University of Applied Sciences for the development of low-emission textiles (sub-goal 3). Among other things, the focus was on alternative manufacturing methods for surface constructions, whereby different machine parameters in the knitting process were tested in addition to various materials and the influence of mechanical and wet finishing processes. The focus was on fleece articles that undergo a particularly stressful mechanical finishing process. You can read about the promising approaches that emerged starting on page 35.

The root cause analysis also showed: Not only the household laundry and the production of surface construction affect microplastic discharge, but also the fabrication of the end product. For this reason, the Hochschule Niederrhein - University of Applied Sciences in close cooperation with VAUDE conducted various experiments with alternative cutting and joining techniques. In addition, the developed materials were tested for their performance and possible harmful substances.

This ensures that the prototypes produced are suitable for the market. You can read more about this aspect starting on page 40.

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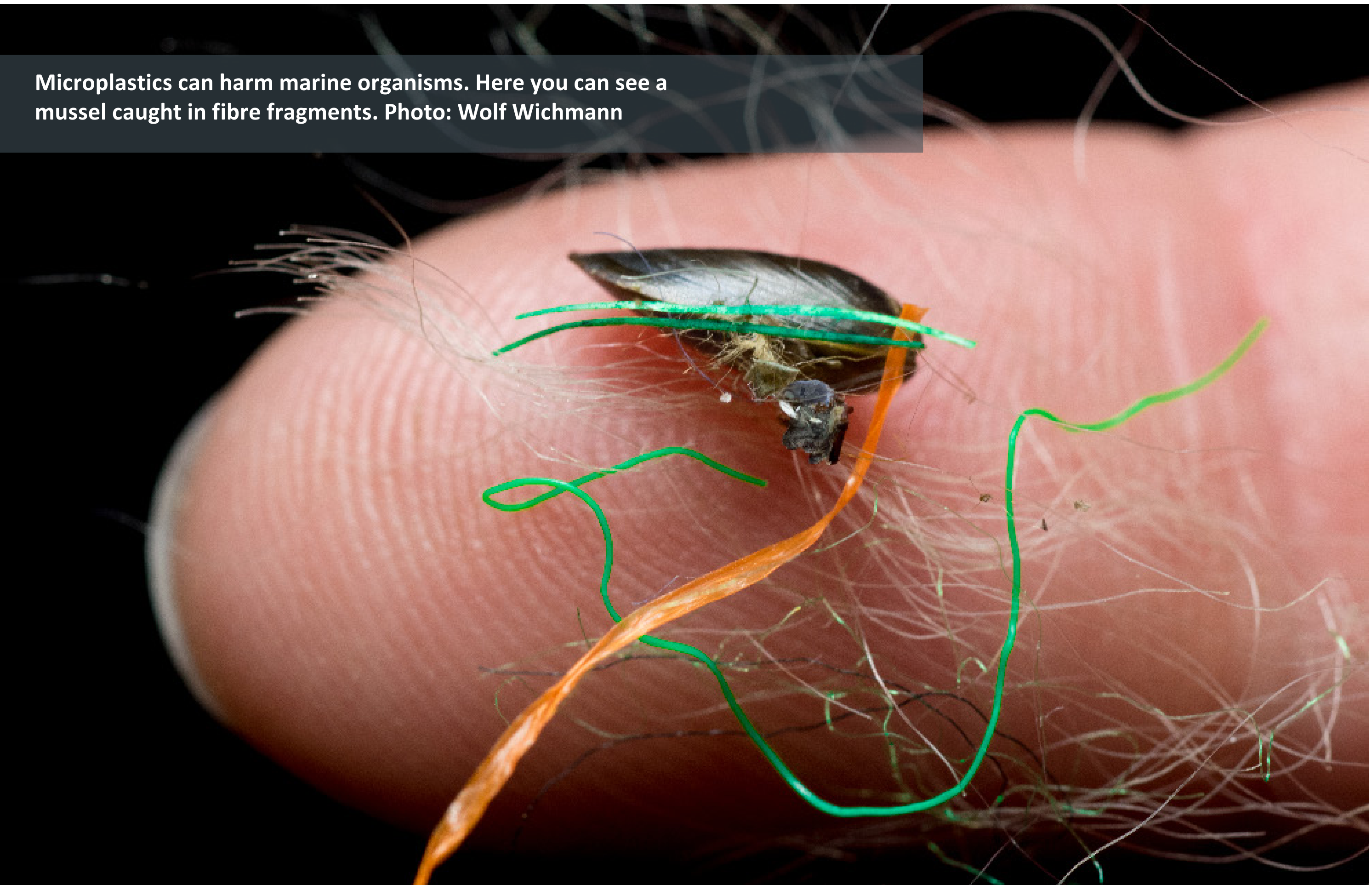

Microplastics can harm marine organisms. Here you can see a mussel caught in fibre fragments. Photo: Wolf Wichmann

SOURCES, EFFECTS, SOLUTIONS

TEXTILE MICROPLASTICS AS AN ENVIRONMENTAL PROBLEM

The problems related to microplastics in the environment have been known scientifically since the 1970s, but have only attracted wider public attention in the past decade. Since then, the topic has repeatedly been at the center of environmentally relevant discussions. The extent and complexity of the problems have become more tangible, not least as a result of intensified research and reporting. At the same time, there remains a great need for further knowledge on the actual extent of the ecological challenge, the effects and the avoidance of microplastics. Only on this basis can long-term, sustainable solutions be developed.

Microplastics can be found everywhere – in all environmental compartments such as water, soil, air and in all ecosystems. Wherever they have been searched for, they have been detected. And where microplastics have not yet been searched for, they are suspected. However, valid data on real concentrations and reliable statements on the behaviour in and effects on the environment, on the basis of these, are currently only rudimentarily available and can vary. This shows how complex the scientific evidence is on the presence and effects of microplastics in the environment. Many data are therefore approximations and estimates, this fact should, however, not be used as an excuse not to take preventive measures now.

THE EXTENT OF MICROPLASTICS IN THE ENVIRONMENT

In 2017, the International Union for Conservation of Nature (IUCN) estimated that between 1.8 and 5 million tonnes of microplastics are released into the environment each year and that between 0.8 and 2.5 million tonnes of it end up in the oceans. A large number of sources play a role here, some of which differ greatly in terms of the quantities released.

In addition to primary microplastics, which are already produced in small sizes, particularly secondary microplastics contribute to the high level of environmental pollution. Secondary microplastics are produced by the abrasion and fragmentation of various plastic products and items, from car tyres to coatings, sports fields and playgrounds, plastic waste in the environment („littering“) and textiles. Regional and national differences in lifestyle and consumer behaviour influence the input of microplastics into the environment in terms of quantity and pathways. Globally, abrasion from urban infrastructure such as road markings and tyre wear, littering and microplastic emissions from textiles appear to be particularly relevant sources.

About 98 percent of emissions of microplastics into the environment are caused on land (see Fig. 1). Once microplastics are in the environment they can spread everywhere. Air and (waste) water in particular are responsible for transporting the small fragments over long distances so that they could be detected even in the most remote areas that are not populated by humans. In addition, the microplastics retained in sewage treatment plants can also be released into the environment through the use of sewage sludge.

Microplastics are now everywhere in the environment. This is problematic because they decompose extremely slowly (up to several centuries), depending on the material and environmental conditions.

EFFECTS OF MICROPLASTICS

Once released into the environment, microplastics can potentially have harmful effects on the living environment. A particular problem with microplastics is their small size as the tiny fragments can easily be absorbed by organisms. At the same time, it is difficult to detect them in the environment and their removal is technically almost impossible.

In recent years, a large number of studies have dealt with the specific effects of microplastics on the environment. Generalised conclusions cannot be made, but the following can be said at this point in time: Microplastics have been detected in various groups of organisms, including mammals, crustaceans, mollusks, insects and birds, especially in the gastrointestinal tract.

The focus of scientific research to date has primarily been on the marine environment, and microplastics have been detected throughout the water column, from the water surface to deep-sea sediments, in coastal areas and even in ice - in different concentrations and compositions of plastic types. The accumulation of microplastics on land and in other environmental compartments has not yet been studied in detail, but initial scientific studies show that microplastics also occur here, for example in soils.

DEFINITION OF MICROPLASTICS

To date, there is no standard definition of the term „microplastics“. Within the BMBF research focus „Plastics in the Environment“, the term is used as „solid plastic emissions smaller than 5 mm“, whereby a distinction is made between nanoplastics (< 1 µm), microplastics (1-1000 µm) and large microplastics (1-5 mm) depending on the size category. Solid plastic emissions can occur as particles, fibres, films or small pieces. Microplastics are also differentiated into primary and secondary microplastics.

This typification is based on the origin of microplastics: while primary microplastics are microplastic particles specifically produced in small sizes and deliberately used in products (e.g. as exfoliants in cosmetics or as abrasives in air-blasting technology), secondary microplastics are first produced by the fragmentation or decomposition of macroplastics / larger plastic particles (e.g. abrasion of textile microplastics from synthetic clothing or decomposition of plastic (waste) in the environment).

Source: J. Bertling et al.: Plastics in the Environment - A Compendium (2021)

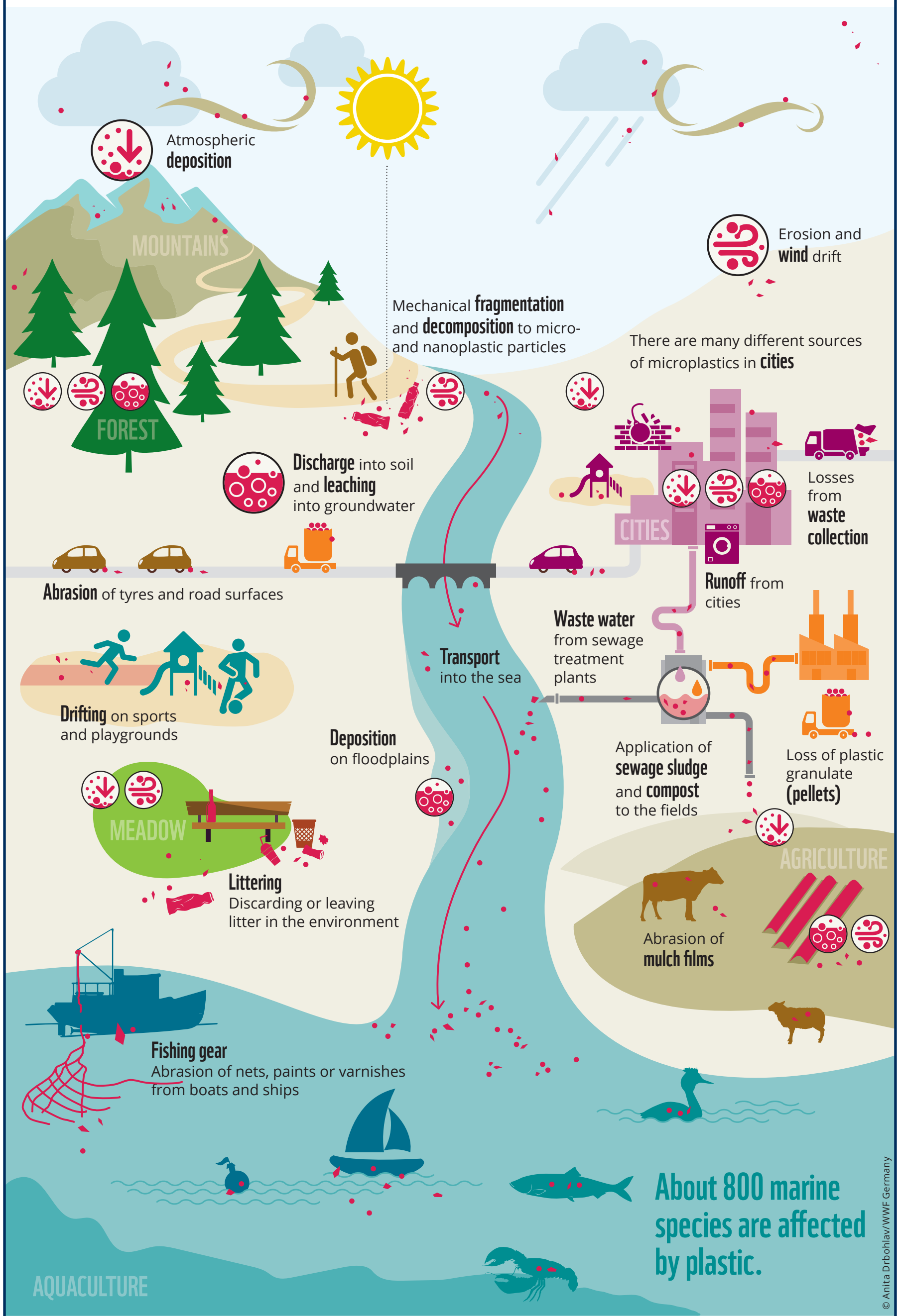

Fig. 1: Microplastics have many sources and enter the environment via different paths. WWF Germany/Anita Drbohlav

Microplastics have even been discovered in newly discovered species in such remote locations as in the Marian Trench, which is more than 10,000 m deep.

The small size and high availability make it easier for animals of even small size to ingest microplastics, for example through their food. Microplastics can affect organisms in two ways: mechanically and indirectly through the added substances (additives). Mechanically, the particles lead to internal injuries, for example injured organs caused by their sharp edges. Indirectly, additives that are not chemically bound to the plastics can be released from the ingested items.

STUDIES OF HARMFUL EFFECTS

Possible harmful effects are currently being scientifically investigated. Studies to date show that microplastics are excreted by some organisms without any apparent effect, while in other organisms, for example, reduced energy intake due to less food, reduced growth or increased mortality have been documented. Studies have also shown that a transfer of additives into blood and organs as well as into fat and muscle tissue can occur and that some additives have hormone-like effects and can thus affect reproduction and sexual development. These results are, however, partly based on laboratory experiments with higher concentrations. To what extent other harmful substances, viruses or bacteria may also be attached to the plastic particles and pass into the animals‘ bodies when ingested is being discussed. Beyond the effects of microplastics on single individuals of an organism, it can be assumed that entire populations and ecosystems can also be affected and thus biodiversity can be impaired.

Microplastics can enter the human body in two ways: through food and through respiration. What effects this has on humans is still largely unknown and there is a great need for research. However, a negative impact on health cannot be excluded.

SPECIAL FORM „TEXTILE MICROPLASTICS“

Textile microplastics are a special form of microplastics. This is mainly due to their specific elongated shape. Textile microplastics are minute pieces of fibre that detach themselves from the main body of (semi-)synthetic clothing. This can be a result of any form of stress. This usually involves usage, the wearing and cleaning of the textile, to which most studies to date also refer. However, as the loss of fibre particles during drying, production, transport and disposal must also be taken into account, as they can represent further relevant sources of microplastics in the environment.

DEFINITION OF „FIBROUS“ TEXTILE MICROPLASTIC

In the framework of the BMBF research focus, fibrous microplastics are defined as particles with a length of < 5 mm that unintentionally enter the environment during the production, care and use as well as the disposal of a fabric/textile. They can be made of synthetic polymers (especially polyester, polyacrylates, PA) or regenerated natural polymers. The term „microfibre“ is often used synonymously with „textile microplastic“.

However, „microfibre“ initially refers to the fineness of the fibre of less than 1dtex (linear density of fibres of 1g/10,000m) and not to the material property. Accordingly, microfibres can be textile microplastics, but do not have to be. Therefore, the term should not be used synonymously.
Photo: Hochschule Niederrhein - University of Applied Sciences, Julius Bonkhoff.

The small fibres can subsequently enter the environment via (waste) water, sewage sludge or the air.

Studies show that the share of microplastic fibres in the marine environment lies at around 20-35 per cent. In coastal sediments the fibre shape was detected even more frequently, accounting for 91 per cent of the microplastics analysed. About 70 per cent were identified as synthetic (mainly polyester) or semi-synthetic, but natural fibres were also represented. The dominance of synthetic fibres in the environment is also reflected in global fibre production, where synthetic fibres dominate the market at almost 65 percent, led by polyester.

SPECIAL FORM - SPECIAL PROBLEMS?

The effects of fibrous microplastics are basically similar to those of particulate microplastics. However, it is assumed that the specific shape may lead to greater environmental damage than regularly shaped particles. The main reason is that fibres compared to particles have a higher surface-to-volume ratio. The relatively larger surface could mean that fibres bind more pollutants and that they reside for longer in the intestine, so that there is also more time for the additives to leak out. In addition, the elongated shape can favour knots and entanglements, which in turn can lead to internal damage in the digestive tract and limited reproduction or starvation. Outside of the body, the swimming ability of animals may be impaired.

THE ROLE OF ADDITIVES

Another important aspect to consider with textile microplastics is the product from which the small fibres are released: Textiles often contain large numbers of additives and chemicals as a result of their many – in some cases non-transparent – production and finishing steps. If fibres are emitted from the textile, the corresponding chemicals dissolve with them and can also be released into the environment. Textile microplastics can therefore be particularly responsible for the transfer of harmful additives into the environment. A study has shown that persistent, bioaccumulative and toxic substances are released into the environment when they come into contact with water.

MANY FACTORS INFLUENCE EMISSIONS

The amount of textile microplastic emissions is determined by various factors: type of fibre, type and quality of the textile surface, age, finishing and refinement of the textile, treatment and many more. Washing brings in additional factors such as the washing programme, type of washing machine or type of detergent used.

The possible use of filters and effectiveness of the wastewater treatment plants are also relevant for determining entry into the environment. All these aspects must be taken into account if emissions are to be reduced.

REQUIREMENTS FOR SOLUTIONS

Given the steady growth of (synthetic) fibre and textile production, it is particularly important to act as quickly as possible - with the clear goal of preventing any emissions of microplastics into the environment at any time and in all stages of the production and life cycle. Due to the complex supply chain, diverse manufacturing processes and multiple influencing factors that cause emissions of microplastics from textiles (into the environment), it is important that certain requirements for solutions are met in order for them to be sustainable. Many factors are still unknown and there is an urgent need for a deeper understanding and concrete figures.

1. Look at the entire supply chain. For meaningful solutions, the entire textile chain must be considered and all possible leakage points must be taken into account. There is a possibility of fibre loss at every step - from fibre production to disposal of the textile. End of pipe solutions alone do not make sense, but they can complement the solution portfolio. Equally unsuitable are solutions that do not address the cause.

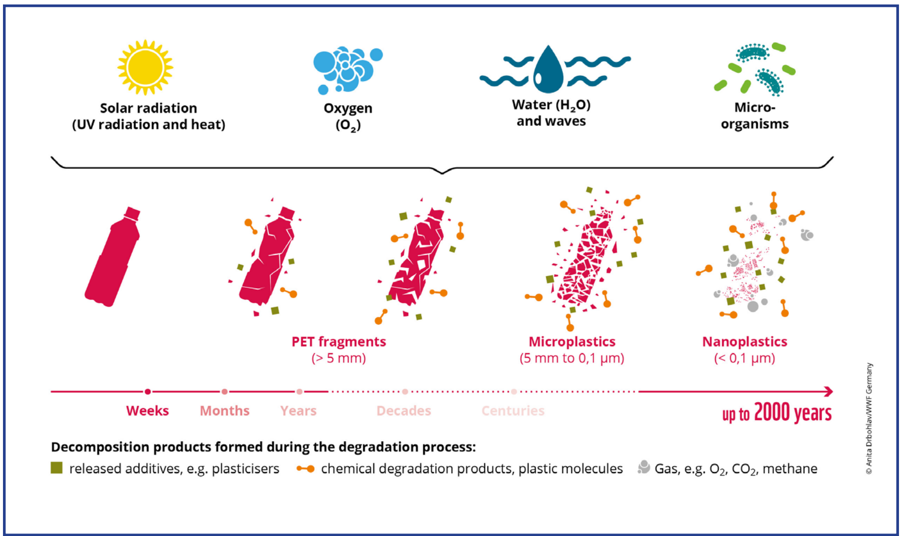

Fig. 2: Duration and form of degradation depend on the type of plastic/ polymer, the additives used and the respective environmental conditions. These lead, among other things, to fragmentation, abrasion, chain scission of the polymer structure and conversion into degradation products. Source: WWF Germany / Anita Drobohlav

Literature:

• *Kraas, C. and Bauske, B. (2020): Microplastics in the environment. Background paper, Berlin.*

• *J. Bertling, C. G. Bannick, L. Brinkmann, L. Barkmann et. al. (2021): Plastik in der Umwelt – ein Kompendium, 1st edition 2021.*

• *De Sa, L., Oliviera, M., Ribeiro, F. et al. (2018): Studies of the effects of microplastics on aquatic organisms: What do we know and where should we focus our efforts in the future? In: The Science of the total environment 15. p. 1030.*

Solutions that start early in the production process may be able to prevent or reduce emissions later on. The largest sources of emissions should also be addressed as a priority.

2. Address the global dimension of the challenge. The textile production chain as a global process with long transportation routes and diverse national production methods and conditions, requires solutions that are as simple and transferable as possible that can be applied effectively in different settings. In the best case, cross-sectoral solutions should be found.

3. Consider all consequences of a „solution“. The corresponding measures should have as holistic an effect as possible. To achieve this, it must be ensured that no negative effects are generated elsewhere („impact shift“). Or that other environmentally sound approaches and measures (e.g. reuse or recycling) are not hindered. The best approaches are those that simultaneously address another environmental issue.

4. Involve all stakeholders in the considerations. For the measures taken, it is the manufacturers and suppliers that are responsible for designing and producing textiles with the lowest possible emissions.

5. Raise awareness and communicate. Appropriate communication about the environmental problem and the approaches to solving it is important in order to generate awareness for both.

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Microplastic test stand at Hochschule Niederrhein - University of Applied Sciences. Photo: Carlos Albuquerque

WASHING AND DRYING TESTS

MICROPLASTIC EMISSION DURING THE HOUSEHOLD LAUNDRY - INFLUENCING FACTORS

Various studies have shown that household laundry is an important entry path into the environment for fibrous microplastics of textile origin. During the washing process synthetic fibres or parts of them are released, they then enter sewage treatment plants via the wastewater system and thus reach the aquatic environment. As part of TextileMission, the Research Institute for Textile and Clothing at Niederrhein - University of Applied Sciences has conducted a broad series of experiments to investigate which washing and textile parameters facilitate the release of fibrous microplastics by household laundry. This resulted in interesting findings for industry and consumers.

Production and consumption of sports and outdoor textiles have risen continuously in recent decades, also within the context of a changed lifestyle, as have consumer demands for products offering a high level of comfort and functionality. The properties required, such as breathability and waterproofing, can be achieved by the choice of material and the construction, but also by the finishing of the textile.

PERFORMANCE-PROPERTIES OF TEXTILES

Depending on the area of application, textiles are constructed very differently. For the outdoor sector, for example, textiles with a heat-insulating effect are required that have a high level of air permeability. Jackets and sweaters are therefore often made of fleece materials. They are bulky and voluminous, warm and at the same time very light. This is achieved by the mechanical treatment of the surface in the finish. Sports shirts and trousers, in contrast, often have a smooth surface that is designed to wick away sweat and dry quickly. Often fibres with very fine fibre diameters (microfibres) are used to achieve high surface density, capillary action and thus good moisture management at low weight.

Polyester (polyethylene terephthalate, PET or PES) is one of the most widely used fibre materials in this sector, as it can be used to achieve a variety of functions. In 2019, 187,000 tonnes of PES were produced in Germany alone.

Worldwide, PES production in this period was around 60 million tonnes. It is therefore not surprising that polyester accounts for the largest share of the fibrous microplastics of textile origin. In addition to the above-mentioned functions, textiles made from these fibres are highly durable and have a long life-span. This is exactly where an ecological conflict arises, which is part of present investigations: The longevity of the product must be ensured and the degradation behaviour in the event of fibre loss must be tested in various ambient conditions.

The aim of TextileMission at the Research Institute for Textile and Clothing at Niederrhein University of Applied Sciences was to investigate the impact of emissions. In order to identify the influence of product manufacture on the release of microparticles, typical textiles and garments made of synthetic material for the outdoor and sports sector were examined.

Fig. 1: The wastewater collected during the various washing experiments was filtered through this filter cascade by the researchers at Niederrhein University of Applied Sciences. The filtrate was weighed and then further analysed. Photo: Carlos Albuquerque

These were mainly knitted fabrics made of polyester filament yarns and polyester staple fibre yarns with different yarn and surface constructions and finishing effects..

MICROPLASTIC EMISSION DURING THE WASHING PROCESS

The general purpose of washing is to freshen up textiles and remove unwanted substances such as fats, proteins and salts. During wear, additional material abrasion occurs, which is removed from the textile together with the dirt and transferred to the wash water. But washing itself also leads to material abrasion and thus to the release of microplastics from synthetic textiles. Overall, the amount of fibres and fibrous microplastic emitted from textiles by household laundry is influenced by a variety of factors and has already been investigated in a number of studies. Comparability between the results of the individual studies is difficult, as the washing and textile parameters are too varied.

SET-UP AND PROCEDURE OF THE WASHING TESTS

The washing parameters (time, temperature, mechanical action and detergent/softener) are in a coordinated relationship with each other. Depending on the washing task and load, they must be set differently in order to achieve a good washing effect on the one hand and to protect the items as much as possible on the other. In the laboratories of Niederrhein University of Applied Sciences, the influence of these parameters on microplastic emission was investigated. For this purpose, different functional textiles and clothes (fleece jackets and sports shirts) made of PES were looked at.

It is known that mechanical stress on textiles often leads to fractures and abrasion. During washing, the textiles are mainly stressed by the contact between the individual laundry items. In order to determine the microplastic emission from polyester textiles during a household wash, sorted loads of washing were washed in household machines under different conditions, at

40 °C using liquid detergent. The following washing parameters were varied:

- Spin speed (900 and 1200 rpm)
- Loading amount (3.5 and 1.5 kg)
- ± Fabric softener
- Time (Easy Care and Express Programme)

After each washing cycle, the washing machines were cleaned twice using the cold wash programme. For control purposes, the resulting detergent alcohols were filtered to measure the fibre load of the water. At the end of a working week, the washing machines were cleaned using a 90 °C cleaning programme.

IN FOCUS: THE DRYING PROCESS

After the washing process, the laundry was dried in two ways: line drying or tumble drying. In the case of line drying, the textiles were dried in laundry bags for 48 hours at room temperature to protect them from particles from the environment. Drying in the dryer took place in standard household dryers using the easy-care programme. Since the textiles were still slightly damp, they were air-dried warm for 20 minutes. During drying in the tumble dryer, the particle emission was recorded via a fibre filter with a cut-off of 200 µm and determined in mg/kg of dried material. Unless otherwise stated, the tests were carried out with a sample size (n) of 3 in order to conduct a statistical evaluation.

5-STAGE FILTER CASCADE

For sample analysis, the entire detergent alcohol of the washing process was collected and filtered. Stainless steel filters with cut-offs of 1500 µm, 500 µm, 150 µm, 50 µm and 5 µm were used (Fig. 1). The amount of fibres emitted was determined and the relative fibre emission in mg/kg textile was calculated. The filtration cascade was cleaned by extensive rinsing after each filtration cycle. After the rinsing cycles, the tube system was freed from aqueous residues by means of compressed air.

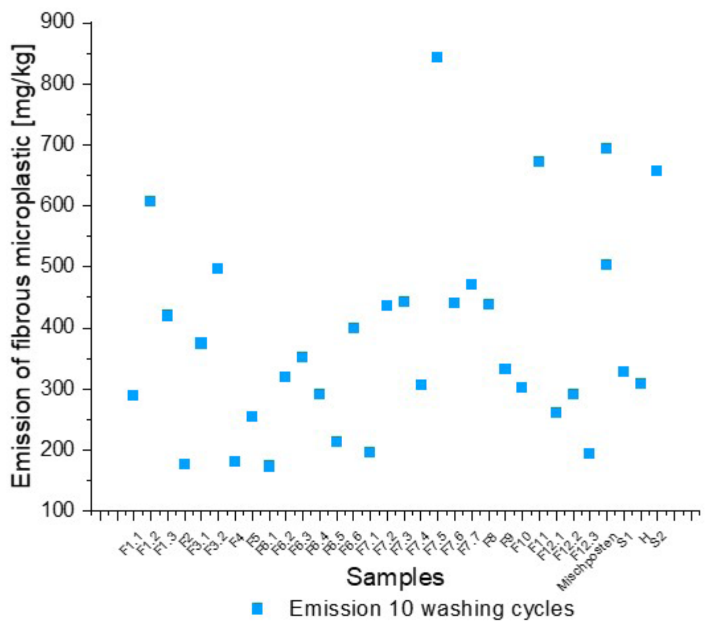

Fig. 2: Overview of the emission values [mg/kg] of the materials tested as the sum of 10 washes (F: fleece fabric, H: plain trousers, S: plain shirt). Source: Niederrhein University of Applied Sciences

At the end of a working week, mechanical cleaning of the tube system was carried out to prevent biofilm formation and to clean off any biofilm that had formed. For selected samples, further analytical methods such as µ- FTIR, microscopy and external TED- GC/ MS measurements were also carried out (FTIR = Fourier transform infrared spectrometer). The textiles were also subjected to a quick material test, which allows an initial assessment of the textile quality.

A total of 23 materials were tested in more than 850 washing trials. The tests carried out reveal a wide range of emission levels; for the present selection of materials, values of 173 mg/kg to 843 mg/kg were determined accumulated over 10 washes, depending on the processes investigated (Fig. 2). For individual washes, the highest value was about 275 mg/kg and the lowest about 6 mg/kg. Analysis of the filter residues using µFTIR and thermal extraction and desorption methods (TED-GC/ MS) showed that 99 percent of the fibres on the filter surfaces were polyester-based.

The remaining one percent consisted of other polymers found, for example, in the zip materials. These results are presented in more detail below with regard to the different aspects of the investigation.

PREDICTION OF PARTICLE EMISSION REMAINS DIFFICULT

For the production of fleece material, the circular knitted fabric is raised on one or both sides (with damage to the textile structure and possibly also to the fibre surface) and optionally sheared to create a soft and voluminous surface to achieve sufficient air insulation (see Fig. 3). The working hypothesis suggested a higher particle emission for mechanically finished goods such as fleece materials than for textiles and clothing articles such as sports shirts made of filament yarns without mechanical finishing and with an intact fibre surface. In order to confirm or refute this hypothesis, the emission values were investigated not only on fleece materials but also on PES goods without mechanical finishing.

As can be seen from Fig. 4, both the fleece and the untreated fabrics show high and low fibre losses, respectively (total over 10 washing and drying cycles). The fleece material F1 and the sports shirt S2 show a comparable fibre emission in both the washing and drying cycles. In comparison, the materials F6 and S1 show a significantly lower emission. It is therefore not possible to determine from a raised or intact fibre surface whether the material has a high or low fibre output. These results contradict common experience and indicate that not only washing itself plays a role in the release of microplastics into the environment, but also preceding processes (see article p. 35).

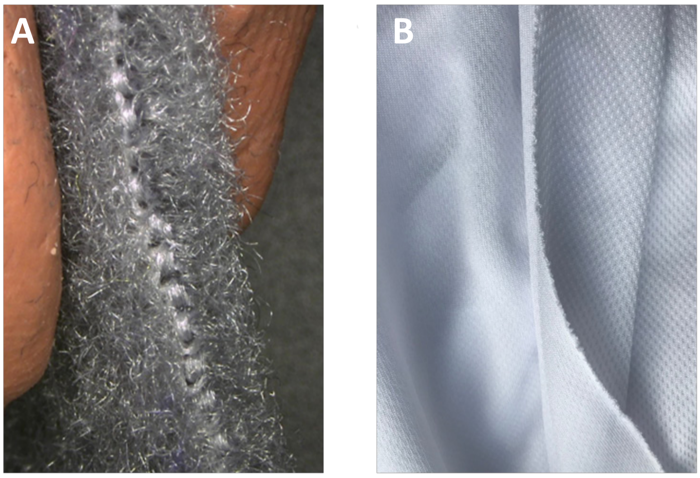

Fig. 3: Illustration of fleece material with raised surface (A) and mechanically untreated material with intact surface (B). Source: Niederrhein University of Applied Sciences

MOST FIBRE FRAGMENTS ON THE SMALLEST FILTER

The evaluation of the different washing cycles showed very varied results. However, it became clear that after filtration of the washing detergent alcohol, most of the fibres were found on the smallest filter (5 µm). This means that the sizes of the fibres released from the materials used in these tests are in the lower micrometer range and fall in the category of „fibrous microplastics“.

Some fibres / fibre fragments were found on the smallest filter that were significantly longer than the size of the pores of the previous filters. However, these fibres have wriggled in the longitudinal direction through the previous filter stages (like spaghetti) because their diameters are smaller than that of the filter pores. In this way, fibres with a diameter smaller than 5 µm could also pass through the last filter and would not be captured. The fibre output was analyzed over 10 washing and drying cycles. The laundry items were washed using the easy-care programme and then dried using a dryer. Both the amount of fibre from the washing process and from the drying process were determined and were quite different for the individual laundry batches. However, the load quantity showed a clear effect, as can be seen in Fig. 5.

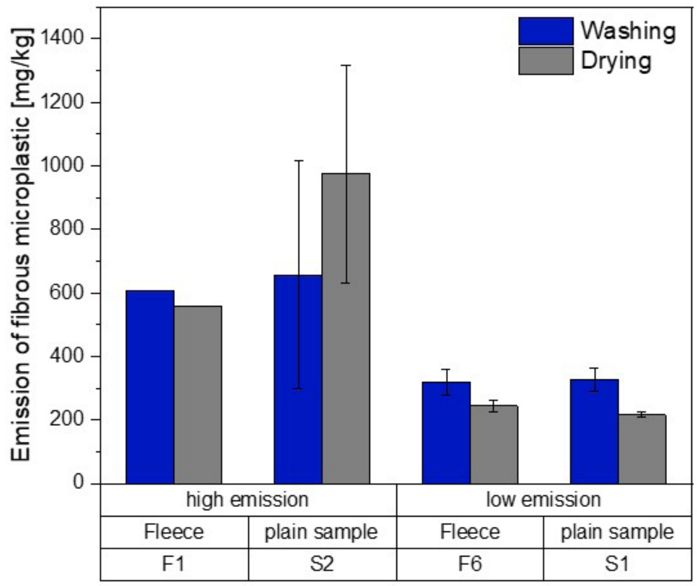

Fig. 4: For both fleece and not raised fabrics, there are samples that show a high and low fibre emission, respectively (sum over 10 washing and drying cycles). Source: Niederrhein University of Applied Sciences

LOWER EMISSIONS WITH A FULL LOAD

It is evident that the fibre emission is always higher with a low washing drum load than with a full washing drum load. On average, the lower load almost doubled the fibre emission. This is due to the higher mechanics in the washing process, since the drop height of the textiles in the drum is significantly greater at lower loads than in a fully loaded washing drum. Furthermore, the ratio of wash water to textiles is higher at lower loads, which leads to a better flow through the textiles and thus higher emissions.

It is also noticeable that the emission from the dryer was generally two to four times higher than the emission through washing. The dryer processes thus also contribute to the emission of microplastics into the environment, even if these do not directly enter the wastewater.

HIGHEST PARTICLE EMISSION AT FIRST WASH

A closer look at the individual washes, for example of article F6 (Fig. 5, integrated picture), showed that the fibrous microplastic emission was highest in the first washing or drying cycle and decreased further and further in the course of the subsequent cycles until it stagnated at around 10 mg/kg for this textile. This trend is characteristic for all washes, with the lowest values from wash 8 onwards generally being between 20 mg/kg and 10 mg/kg. In all washing tests over the sequence of ten washing cycles, it could not be observed that the fibre load increased again. An increase in the plastic content due to material aging or increased abrasion in the washing machine does not seem to occur with the materials of very durable polyester fibres in the course of 10 washes. Drying in a tumble dryer resulted in a higher overall fibre discharge (washing and drying process). The investigations carried out reveal a wide range of emissions.

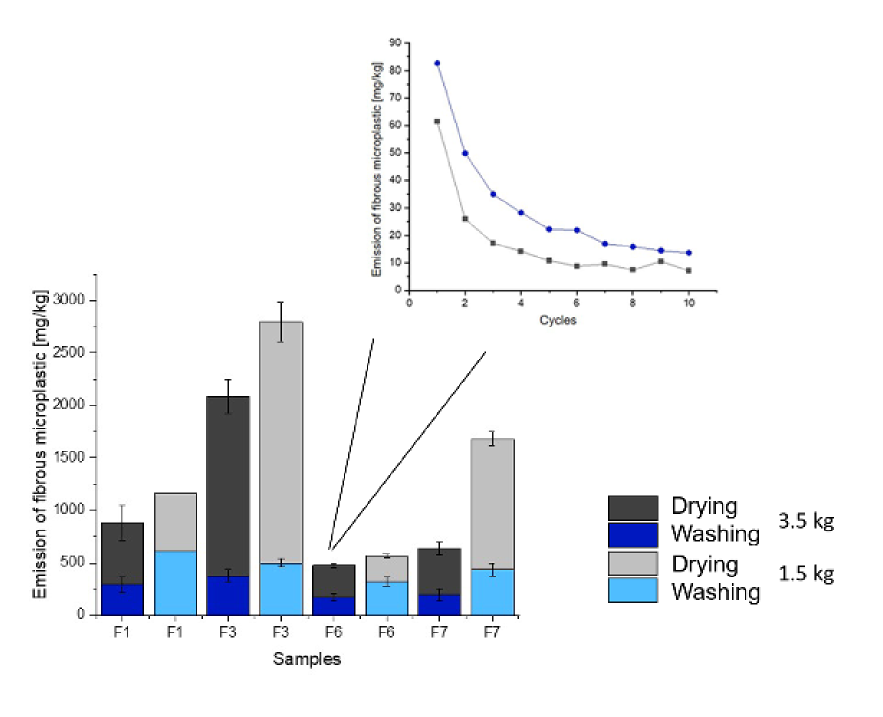

Fig. 5: Fibre emission of different fleece fabrics at different loads in the washing machine (1.5 kg and 3.5 kg) and the dryer, summed over 10 cycles each. Integrated image: Distribution of fibre emission per cycle using the example of a fleece fabric. Source: Niederrhein University of Applied Sciences

THE EFFECTS OF DRYER, FABRIC SOFTENER AND WASH PROGRAMME

Depending on the parameter investigated, values of 75 mg/kg to 3948 mg/kg were determined for ten drying cycles. If the laundry was dried on the line, the total fibre load was lower than with drying in the dryer. However, more fibres entered the wash water in the subsequent washing process, since loose fibre fragments that were not rinsed out during the washing process remained in the material and were not removed by the dryer. During drying in the dryer, these fibres were collected in the lint filter and could not enter the wastewater. An effect of fabric softener on fibre release could not be clearly determined. Increasing the spin speed from 900 rpm to 1200 rpm did not lead to an increased fibre emission. The choice of wash programme, on the other hand, can have a slight influence on the fibre output. The use of the express programme at low washing time (run time 30 min, spin speed 1200 rpm) showed a slightly lower fibre removal compared to the easy care programme (run time 1h 59m, spin speed 1200 rpm). The most probable explanation: With a reduced washing time, the laundry is less mechanically stressed, which may be responsible for the reduced fibre emission.

RESULTS POINT TO PRODUCTION RESIDUES

The course of the curves for particle emission in washes shows a characteristic course for all the materials investigated. 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.

CONSUMER TIP - FULLY LOAD THE WASHING MACHINE!

Select a load for the washing machine that does not subject the textile to high mechanical stresses, but at the same time provides a sufficient washing effect. The following applies to microplastic emission: the fuller the better!
Shorter washing times also contribute to a reduced emission, but here, too, the washing effect must be adequate.

The fact that the polymer-chemical composition of the filter residues contains clear indications of polyester also suggests that the residues are inherent to the material and not foreign fibres or impurities from transport or storage. For the samples considered here, it should also be noted that articles with a mechanical destructive finish such as raising and shearing do not perform worse than articles that have not undergone any mechanical finish.

If all the input pathways for microplastics identified in the project are added together, the picture shown in Fig. 6 emerges.

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- *www.statista.com*
- *J. Bertling, C. G. Bannick, L. Brinkmann, L. Barkmann et. al. (2021): Plastik in der Umwelt – ein Kompendium, 1st edition 2021.*

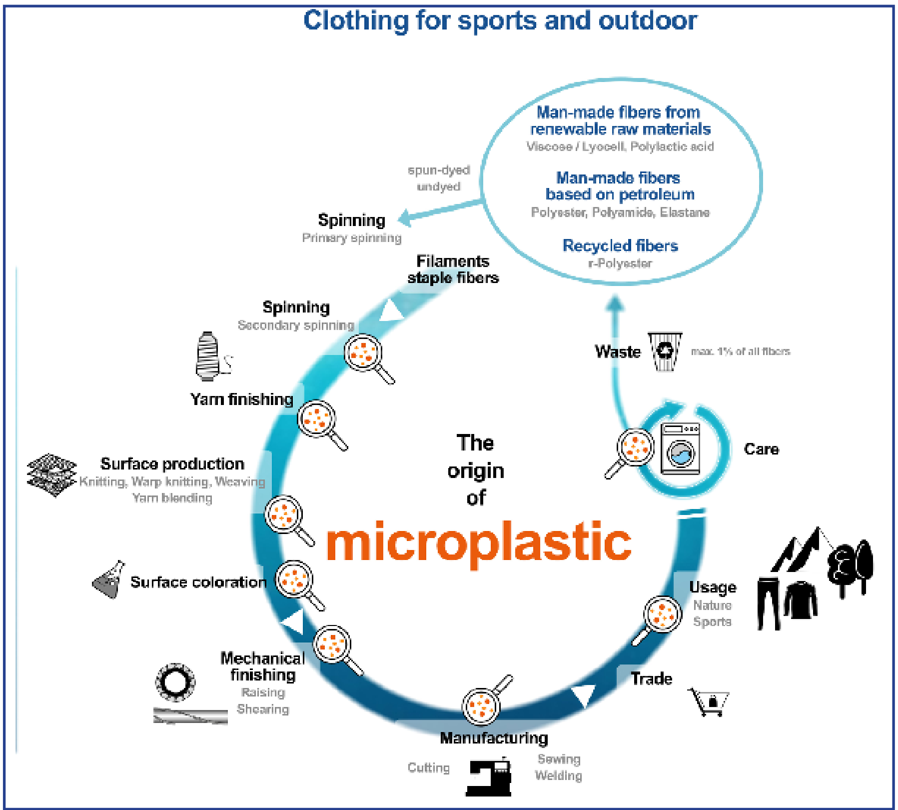

Fig. 6: Fibrous microplastics are released at different stages of the value chain and during the utilisation phase of a garment. Source: Niederrhein University of Applied Sciences

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ENVIRONMENTAL IMPACT OF TEXTILE MICROPLASTICS

QUANTIFICATION, FRACTIONATION AND RETENTION IN WASTEWATER TREATMENT PLANTS

How do textile microplastics behave after they have entered wastewater via household laundry? Is the retention of textile microplastics in wastewater treatment plants dependent on the size of the fragments? These questions were addressed by the Institute for Water Chemistry at the TU Dresden. In addition, research was also conducted on the biodegradability of different fibre types and the influence of various additives from production.

Synthetic textiles, which release microparticulate fibre fragments during production, wear and laundering, are considered a major source of microplastics. At the start of the project, it was unclear to what extent microplastics are released from textiles via household laundry and how many of them enter the environment. The core questions of the research activities at the Institute of Water Chemistry at the TU Dresden were derived from this: Are textile microplastics efficiently retained by wastewater treatment plants on a laboratory scale? And how does the size of the particles influence this?

METHOD DEVELOPMENT

In order to address these overarching questions, a method was developed to fractionate and characterize fibre fragments according to size (e.g. size, number, polymer type, ...). The method was limited to polyester (exactly: polyethylene terephthalate, PET), which is the most commonly used synthetic polymer for textiles in terms of quantity. In addition, the biodegradability of various fibre materials and the influence of textile additives (dyes, plasticisers, antimicrobial finish) were investigated.

EXTRACTION OF THE FIBRE FRAGMENTS

First of all, it was necessary to obtain a sufficient quantity of fibre fragments that could later be analysed under the fluorescence microscope. For this purpose, commercially available white fleece pullovers were washed in numerous washings and the wastewater was filtered through a five-stage filter cascade, with a mesh size of 1500 to 5 µm. According to the mesh size of the filters, the emitted fibre fragments could be separated into five nominal size fractions:

- > 1500 µm
- 1500 - 500 µm
- 500 - 150 µm
- 150 - 50 µm and
- 50 - 5 µm.

The collected particles were identified as PET polymers by FTIR analysis. In this way, contamination of the samples by foreign substances could be ruled out. This allowed the specific behaviour of textile microparticles to be investigated in a more differentiated manner (see Fig. 1).

ANALYSIS OF THE MICROPARTICLES: SIZE FRACTIONS

The microplastics on the filters with mesh sizes of 150, 50 and 5 µm were microscopically charac- terized with respect to their actual size distribution. For this purpose, extensive method validation was performed to obtain, among other things, the influence of re-suspension, particle concentration and the size of the sample to be counted. In Figure 2, fibre abundance is plotted against fibre size (or size range). Fibres covering a very wide range of sizes can be found on the filters with different mesh sizes. For example, the maximum fibre abundance is 150-200 µm on the 150 µm filter, 100-150 µm for the 50 µm filter, and >0-50 µm on the 5 µm filter. The characterized size fractions were used for the further experiments. Obtaining a few grams of the size fractions and characterizing them took many months.

RETENTION OF FIBRES IN THE LABORATORY WASTEWATER TREATMENT PLANT

Wastewater treatment plants have different mechanical, chemical and biological treatment stages. These have been reproduced in laboratory tests. They included, for example, the co-sedimentation of PET size fractions with primary and activated sludge. The aim of this experiment was to determine the proportion of PET fibres retained in the sludge matrix of a wastewater treatment plant and whether the size of the fibres influences the retention.

The results show that the average mass of fibres in the settled activated sludge was 98 percent for size fraction B (1500 - 500 µm) and 87 percent for size D (150 - 50 µm). In the primary sludge, the average co-sedimentation of fibres was 97 percent for size fraction B and 99 percent for size fraction D. Overall, the amount of fibres retained in the sludge was significantly higher ($p<0.05$) than that of fibres in the wastewater effluent (i.e., supernatant 1 - 10 percent). The size of the fibres did not affect their potential removal by solids ($p>0.05$).

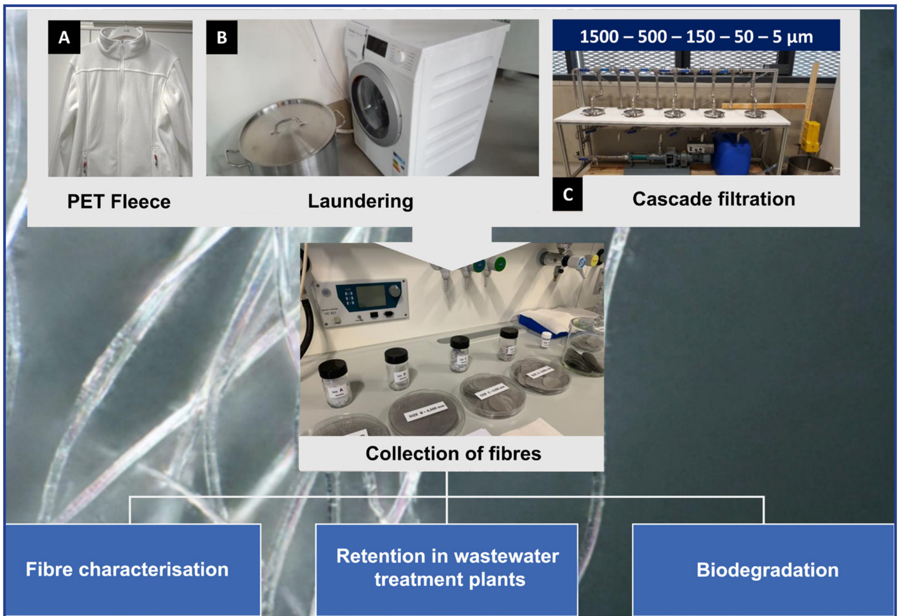
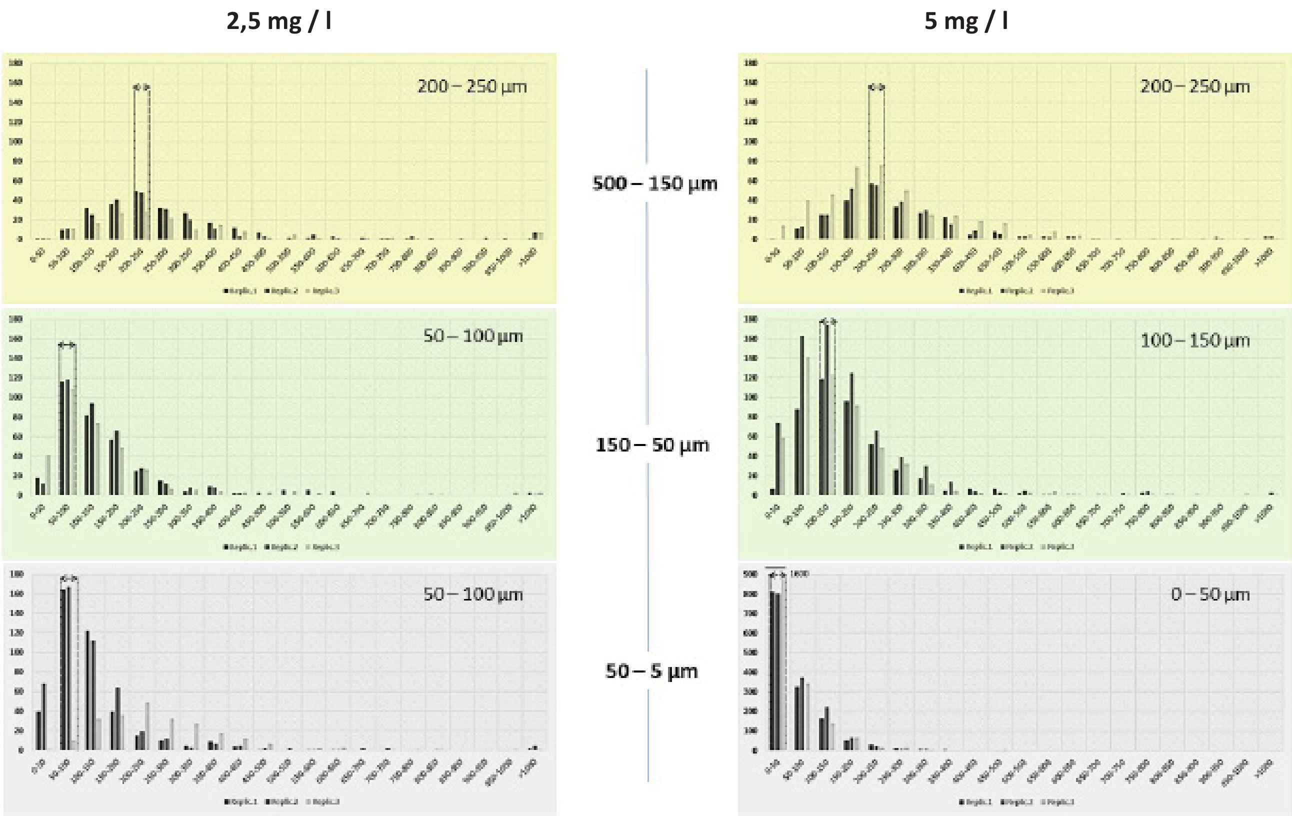


Fig. 1: TU Dresden work packages - Commercially available fleece pullovers were first washed and the waste water was filtered in a five-stage filter cascade. The fibre fragments obtained this way could be used for various test series. Photos: Yaqi Zhang, TU Dresden



y-axis: fibres in numbers (n = 3); x-axis: fibre size intervals [in length, µm].

Fig. 2: Example of filtration analysis of PET fibre fragments originating from fleece household laundry. Fibres were collected through cascaded stainless steel filters (1500 - 5 µm). Retained fibres were processed in suspensions and fibre lengths were characterised by subsampling (n=3). The peak fibre abundance of each treatment is shown in the graphs. Source: TU Dresden

In water treatment, so-called coagulants such as aluminium sulfate ($Al_2(SO_4)_3$) are used to remove particulate contaminants. In the experiments carried out, the removal of the different size fractions was investigated by means of inclusion folding and different concentrations of the coagulant (1 mg/L, 7 mg/L and 15 mg/L). 79 to 94 percent by weight of the PET fragments could be removed in this way.

BIODEGRADATION OF SELECTED FIBRE MATERIALS

Another object of investigation was the biodegradability of various textile polymers in the form of fibre fragments, including:

1) PET
2) oxo-degradable PET
3) Mixed fibre sample of PET/cotton
4) Cotton
5) Viscose

The viscose fragments were additionally provided with so-called textile finishing chemicals (dyes, softeners and antimicrobial finishes) in order to better understand their influence on the biodegradability of fibres.

A Degradation of fibres commonly used in the textile industry: In tests on the rate of biodegradation, cotton and viscose fibres were found to mineralize by about 70 percent within 60 days under aerobe conditions (Fig. 3). This result indicates that these fibre fragments are also degradable in the environment if conditions are similar to those in the laboratory test. No biodegradation was observed for PET and „oxo-degradable PET“ under the same conditions. The mixed fibre sample of PET/cotton (ratio 60:40) shows a percentage of degradation that can be attributed to the cotton portion of the fibre (Fig. 3).

Degradation of modified fibres treated with different textile finishing agents: The biodegradability of viscose fibres and viscose fibres treated with two different chemical dyes, namely Avitera (Av-) and Remazol (R-), and a softener were compared. The biodegradability of the viscose fibres was not affected by these additives (see Fig. 4). Using the example of RUCO-BAC, an antimicrobial finish that reduces the odour formation of, for example, sports textiles, it could be shown that textile finishing can have a strong influence on biodegradabili-

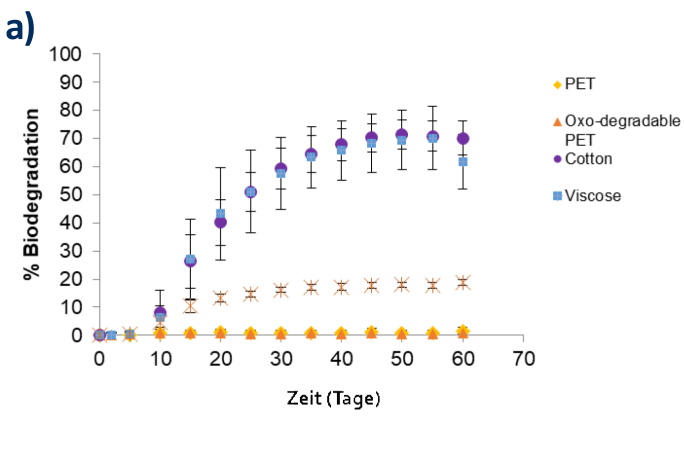


Fig. 3: Biodegradation of various fibre materials commonly used in the textile industry over a test period of 60 days. The results were calculated in each case as mean values of two sets of triplicates. The black bars represent the standard error (n = 6). Source: TU Dresden

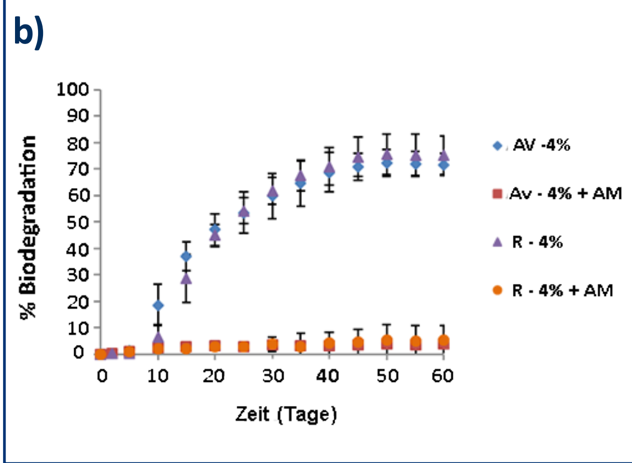


Fig. 4: Biodegradation rates of two viscose fibres finished with the dyes Avitera (Av-) and Remazol (R-) and of another two additionally with antimicrobial agent (RUCO-BAC) over a period of 60 days. The black bars represent the standard error (n=6, except for R-0.25% AM with n=3). Source: TU Dresden

ty - and thus on the persistence of the fibres. In this example, the biodegradability of the viscose fibre was almost completely inhibited.

CONCLUSIONS

Taking up the key question formulated at the beginning, it can be concluded from the laboratory tests that textile microplastics from PET are presumably almost completely retained by wastewater treatment plants (> 95 %) - this is in good agreement with other current studies on microplastics in wastewater treatment plants. In the tests carried out, no or only a slight dependence on size was found; however, both statements refer only to the size fractions investigated.

Nevertheless, it can be assumed that a small part of the total microparticle load can be emitted into the aquatic environment via the wastewater treatment plant effluent. In this context, the emission of fibre fragments to natural waters via the wastewater treatment plant was estimated (Fig. 5). For this purpose, published emissions of textile microplastics from washing tests with synthetic textiles were used and related to a cohort of 100,000 inhabitants. Only fibre abrasion in the first wash cycle was considered and since the first wash is generally associated with the biggest emission of fibres, this estimate represents a „worst case scenario“.

For the wastewater treatment plant, a removal of 95 percent of the textile microparticle load was assumed. It is estimated that 0.04 to 11.8 kg of textile microplastics are emitted into the aquatic environment via wastewater treatment plants per day and per 100,000 inhabitants. For Germany with 83 million inhabitants, this results in emissions of 2 to 49 tons per year. The microparticle emissions resulting from the application of activated sludge to agricultural fields were not subject of the studies.

Biodegradability tests have confirmed that PET fibre fragments from the fleece wash were not biodegradable during the test period of 60 days. In addition, fibres such as pure viscose were found to be biodegradable as expected, but with surface finishing (such as the dyes, softeners and antimicrobials tested in the study), the biodegradability of the materials was reduced. In particular, the presence of an antimicrobial agent significantly reduced the biodegradability of viscose. The results suggest that the time the released fibres remain in the environment could vary depending on the different surface additives applied during manufacture. This should be considered in future research to better understand the environmental impact of fibrous microplastics from synthetic textiles.

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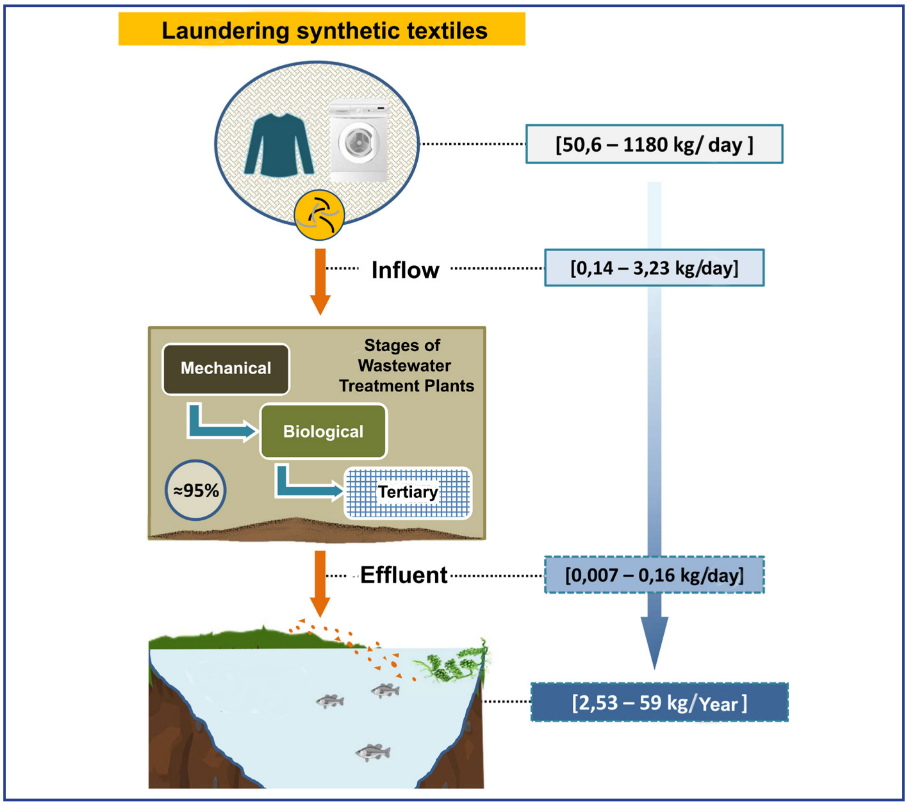

Fig. 5: Estimated total amount of fibre emission from household laundry per 100,000 inhabitants that is discharged into the aquatic environment via sewage treatment plants. Source: TU Dresden

IS AN ADDITIONAL PURIFICATION STAGE IN WASTEWATER TREATMENT PLANTS RECOMMENDABLE?

Expanding existing wastewater treatment plants by adding a fourth treatment stage with the aim of further eliminating micropollutants is currently being discussed in Germany. Favoured technologies are mostly oxidation with ozone or adsorption using granulated or pulverized activated carbon. Some treatment plants have already been upgraded accordingly.

The granulated activated carbon has removed about 61 percent of microplastics from the water (Wang, et al. 2020). Hidayaturrahman and Lee (2019) also found that the use of ozone is a promising approach for removing microplastics. Nevertheless, further research on the efficiency of these treatment methods is recommended, as the removal of microplastics seems to depend mainly on the size and shape of the particles.

In addition, such a technical expansion of wastewater treatment plants can be associated with considerable investment and maintenance costs, as more energy and chemicals or materials are required. Such a step could be considered especially for regions suffering from a particularly high microplastic load. For such a decision, systematic environmental monitoring and risk assessment would be necessary to gain a better understanding of the (still) environmentally acceptable emission level in each case.

One scenario in which microplastic emissions can abruptly be considerably increased is overflow in wastewater treatment plants, which can occur due to a lack of hydraulic capacity during periods of heavy rainfall. In this context the modification of the existing infrastructure with regard to control and reduction of wastewater overflows seems to be an important aspect (ECHA and US Environmental Protection Agency).

Authors:
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Taher Alrajoula, BSI e.V..

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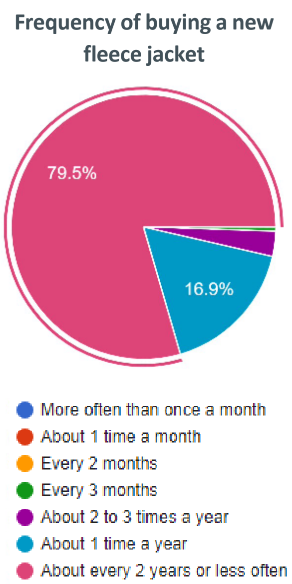
MASS BALANCE ANALYSIS

HOW MANY MICROPLASTICS FROM SPORTSWEAR END UP IN THE ENVIRONMENT

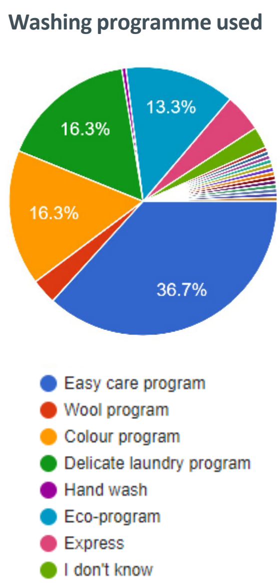
A mass balance analysis was carried out to obtain a more accurate picture of the extent of the environmental impact of textile microplastics in Germany that is generated when sportswear is washed. The calculations included the results of a consumer survey on washing behaviour conducted as part of TextileMission, as well as various other data collected in the course of the project.

How often do consumers in Germany buy new sportswear? How do they wash and dry the items? And how long do they use the clothing on average? These and other questions were part of a consumer survey conducted by the Association of the German Sporting Goods Industry as part of TextileMission. The results were intended to provide data for calculating the microplastic emissions in Germany, for which sportswear made of polyester in particular is responsible. The priority was given to fleece jackets and running shirts because they were also in the focus in other parts of the project.

The consumer survey focused on the target group of active athletes. Around 67 percent of the respondents exercise regularly (several times a week), about 19 percent of them do so at least once a week. The total of 260 participants ranged in age from 16 to 70 years. Women represented 58 percent of the participants and men 42. The survey included questions about the washing frequency of the items and their disposal, in order to assess the effective lifespan of the garments and the extent of their contribution to the overall particle discharge. Here are some key results:



Washing frequency: Once every two months on average with the following parameters



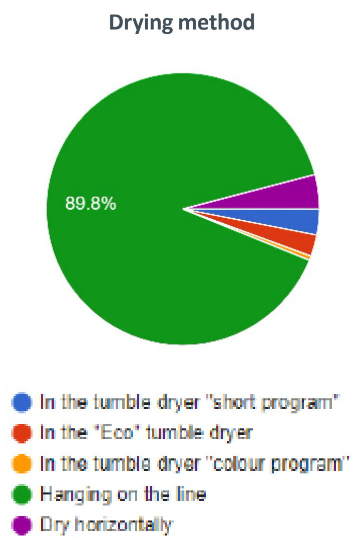
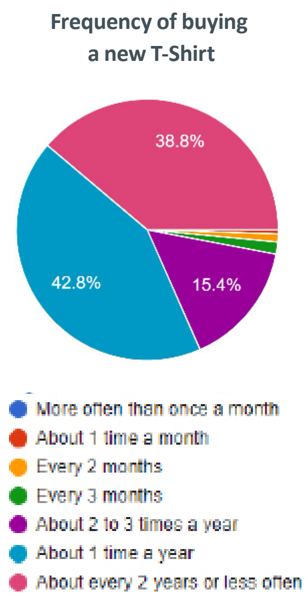
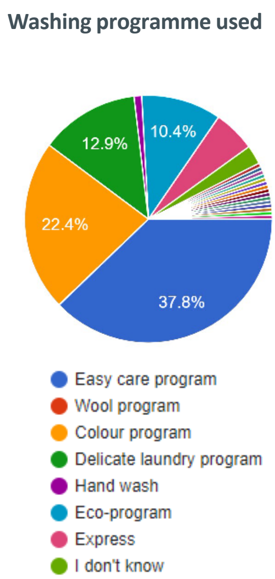


Fig. 1: The results of the consumer survey show that respondents only buy new fleece jackets every two years or less. On average, the items are washed once every two months, with the easy-care programme being used most frequently. Nine out of ten respondents usually choose line drying. Source: BSI e.V.



Washing frequency: On average three times per month with the following parameters



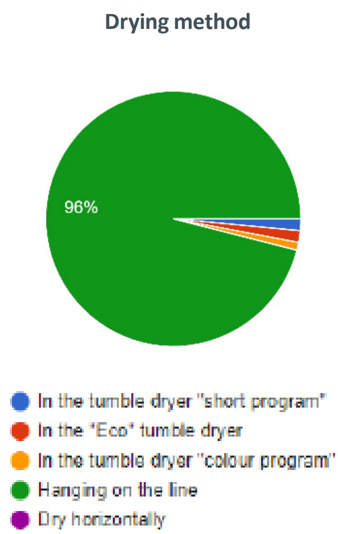


Fig. 2: The results of the consumer survey show that 80 percent of respondents buy a new sports T-shirt once a year or more. On average, the items are washed three times a month, with the easy-care programme being used most frequently. Almost all respondents usually choose line drying. Source: BSI e.V.

- The majority of respondents indicated that they wash their items before the first use;
- Fleece jackets are washed on average once every two months and running T-shirts three times a month;
- Around 37 percent of owners of both types of sportswear use the easy-care programme when washing. The rest use various other washing programmes;
- 90 percent of consumers usually use line-drying for their laundry;
- 76 percent of respondents load the washing machine fully, only 24 percent do so only halfway.

In addition, respondents were also asked to provide information on the number of individual items they own, how often they purchase them and how they dispose of them:

- Around 80 percent buy a new fleece jacket within a period of two years or less;
- Forty-three percent of running shirt owners buy an item once a year, while 39 percent do so every two years or less;
- 54 percent of fleece jacket owners dispose of the items in the used clothing container, 17 percent donate the jackets and about 14 percent give them to others.
- The results for running T-shirts were similar, with 56 percent of owners throwing articles into the used clothing container.

EXTRAPOLATION TO THE NATIONAL LEVEL

DThe results of the survey served as a basis for calculating the total PET release from household laundry in Germany. Various other influencing factors had to be taken into account. The number of active athletes within the German population in 2019 was used to estimate the total number of polyester upper-body sportswear articles and their washing frequency: According to the Federal Statistical Office, 11.67 million people were active in sports several times a week and 15.27 million were active several times a month.

In addition, the difference between imported and exported sportswear for 2019 was included in the calculation for each type of sportswear covered in the project. In addition, other data were included, such as the assumed number of sports textiles worn by non-athletes and the estimated frequency of their washing. The results of the survey were subsequently linked to the results of the washing tests at the Hochschule Niederrhein - University of Applied Sciences. The following aspects were of particular interest for the mass balance analysis.

For fleece materials: In the context of this project as well as in other previous studies, it was shown in the laboratory that the detachment of textile microplastics decreases with the number of consecutive washing cycles. Thereafter, the discharge stabilizes at a certain point, which was found for fleece materials to be after the tenth wash cycle (Pirc et al. 2016). This is also consistent with the laboratory tests conducted as part of TextileMission. The lifespan of fleece jackets therefore plays a role in their microplastic balance and consumers can make an environmentally positive contribution by using the product as long as possible. It was assumed that fleece jackets are disposed of after six years of use (36 washes). The first ten washing cycles of the fleece jackets at Hochschule Niederrhein - University of

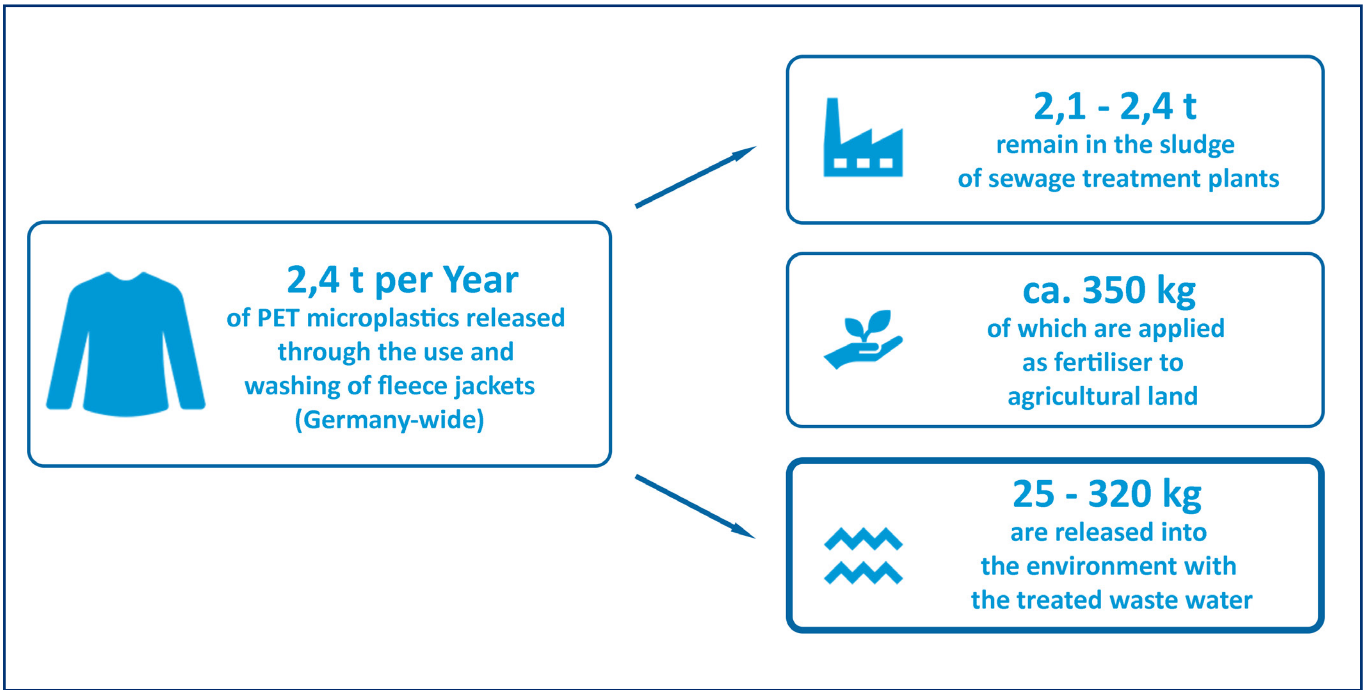


Fig. 3: In order to estimate the number of fleece jackets in circulation, the number of active athletes as well as import and export data were taken into account. Furthermore, the results of the washing tests at Hochschule Niederrhein - University of Applied Sciences were included in the extrapolation. Source: BSI e.V.

Applied Sciences released an average value of 250 mg/kg of microplastic fibres, if the dryer was used once between every two washing cycles and the household washing machine was loaded with a high load. The average discharge was afterwards about 10 mg/kg per wash cycle.

For running T-shirts: The calculations for running T-shirts made of polyester, were based on the microplastic emissions data from De Falco et al. (2019). As mentioned earlier, the survey found that athletes wash T-shirts on average three times per month. Further considerations of the stability of emissions after the tenth wash, disposal by the 36th wash and the factors of laundry drying and wash load (described below) were also used for this article.

Other polyester upper-body garments were not the focus of the project and few meaningful laboratory tests were conducted for them. However, in order to provide a complete picture of PET release during washing, these fabrics were included in the study and an estimate was made on the basic PET release rate.

LINKAGE WITH OTHER PROJECT RESULTS

The washing parameters used in the laboratory experiments (temperature, spin speed, type of detergent) to investigate PET release when washing fleece jackets at Hochschule Niederrhein - University of Applied Sciences were compatible with the washing parameters most commonly used by the respondents. This included also the non-use of fabric softener. The results of the laboratory experiments can therefore be considered representative and scalable.

The experiments in the laboratory were carried out using two methods: With a full load of the washing machine and with a half load, whereby it turned out that the emissions were higher by a factor of 1.9 with a half load than with a full load. This could be explained by the increased mechanical effects caused by the lower load. On the other hand, another explanation could be the effect of increased water volume on the textile. Kelly et al. (2019) reported that the high water volume-to-textile ratio was the most influential factor for the release of microplastic fibres, rather than mechanical friction (fibre-to-fibre). In the end, everyday practice is relevant to the mass balance analysis. According to the survey, 76 percent of the people load the washing machine completely and the rest only half. This ratio was taken into account accordingly in the extrapolation.

The laboratory experiments at Hochschule Niederrhein - University of Applied Sciences also showed that line drying - which, according to the survey, is used by more than 90 percent of respondents - resulted in an increased PET emission factor of 1.5. This factor was used in the extrapolation (under the simplified assumption that all people use line drying).

The laboratory tests at Hochschule Niederrhein - University of Applied Sciences indicate that low-priced fleece jackets are generally of lower quality and therefore emit more fibre fragments. However, most respondents in the above-mentioned survey described the quality of the fleece jacket they used as „high“. In the calculation, the above-mentioned average value of fibre emission was taken into account, as it is compatible with the results of the survey. The number of experiments for a wide range of clothing commonly available on the market also represents another source of reliability of the results. Subsequently, the total amount of PET microplastics emitted by the use and washing of fleece jackets on a national level (for a population of 83 million) was estimated at about 2.4 tons per year. The figure for running T-shirts is about 2.5 tons per year. If the estimated emissions of the other upper-body sportswear items are added, this results in an amount of about 10.3 tons per year.

TOTAL PARTICLE DISCHARGE

The simulation of wastewater treatment on a laboratory scale at the TU Dresden showed that the treated wastewater still contains 1.0 - 13 percent of the PET fibres in the range from 50 to 1500 µm in length. The remainder settle down in the sewage sludge. If one considers that - apart from exceptional cases such as overflow during heavy rain events - almost all wastewater in Germany ultimately finds its way into sewage treatment plants, then the corresponding annual quantity of PET entering the environment via sewage treatment plants is in the range of approx. 25 - 320 kg each for fleece jackets and running T-shirts and 100 - 1340 kg for all upper-body sportswear.

Considering the large volume of regulated wastewater in the whole federal territory (about 9000 million m3 per year according to the Federal Statistical Office), the resulting concentration of total PET will be in the range of 0.011 µg/L - 0.15 µg/L. Certainly, this is only one source of PET and it should be noted that this is an accumulating value that increases from year to year taking into consideration the persistence of these particles as shown by the experminets of TU Dresden. Treated wastewater with such a PET concentration is mainly discharged into freshwater systems in rural areas, where the content is further diluted. Some of these particles are also retained in rivers (depending on river length, hydrology, particle density, etc.), exported via freshwater withdrawals for various uses, or eventually enter the marine environment. Estimating the environmental risk for different millieus is therefore difficult and requires additional research on the transport and fate of these particles.

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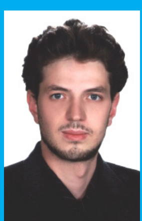

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EFFECTS OF TEXTILE MICROPLASTICS - PET CONCENTRATION IN THE AQUATIC ENVIRONMENT

The toxicology of textile microplastics is an area in which relatively little research has been conducted to date. However, initial studies already provide an idea of the concentration of PET in aquatic environments at which negative effects on the organisms living there are to be expected. In the studies cited here, adverse effects are not caused by ingestion of the particles, but by stress during physical contact.

Jemec et al. (2016) found that 48-hour exposure to PET microplastics of textile origin at concentrations of 12.5 to 100 mg/L (fibre length 62 - 1400 µm) in freshwater environments resulted in a mortality of 20 to 40 percent (without pre-feeding) and < 10 percent (with pre-feeding) in the large water flea Daphnia magna. Ziajahromi & Kumar et al. (2017) investigated the toxicity of microplastic fleece particles (100% polyester) of length 26 - 1150 µm (dominant in the range 100 - 400 µm) in freshwater fleas Ceriodaphnia dubia. They showed the following toxicity:

• LC50 (half lethal concentration, 48 h exposure): 1500 µg/L
• EC50 (half maximum effective concentration, reproduction, 8-day exposure): 429 µg/L.
• LOEC; the lowest observed effect concentration (growth in adult individuals, 48 h exposure): 500 µg/L.

MICROPLASTICS AS CARRIERS OF OTHER POLLUTANTS

It should also be noted that some microplastic particles are potential carriers for pollutants that accumulate on them. Examples include pharmaceuticals, PAHs (polycyclic aromatic hydrocarbons), organics, metals such as cadmium (Cd), lead (Pb) and zinc (Zn) due to their negative charge, and pathogenic bacteria. In addition, other harmful additives used in the textile industry, such as water repellents, stabilizers, plasticisers and flame retardants, are partly not chemically bound to the plastics and can therefore be easily dissolved out and pollute the environment.

The corresponding total surface area of the particles at the above concentration (assuming that all PET fibre fragments have a cylindrical shape) is three to 46 mm² per cubic meter of water, with an average PET fibre density of 1.3 g/cm³ and a fibre diameter of 10 µm. At the same time, however, it should be noted that the adsorption of these pollutants and the ability to transfer them to organisms has not yet been well studied and requires further research.

PET CONCENTRATION IN THE SEWAGE SLUDGE

The spreading of dried sewage sludge on agricultural land in Germany is decreasing from year to year due to safety concerns. The amendment to the sewage sludge ordinance of 2017 further restricts agricultural utilization. The transition period ends 1. January 2029, for facilities designed to serve more than 100,000 residents and 1. January 2032, for facilities designed to serve more than 50,000 residents. In 2018, the total amount of sewage sludge in dry mass was circa 1,750,000 t, of which approx. 280,000 t (16 percent) were applied to land. Assuming that treatment of sewage sludge prior to application to the land (e.g. sludge thickening) does not reduce microplastic content, the amount of PET from upper-body sportswear introduced via this pathway would be in the range of 0.005 g/kg (see the above calculations).

According to the Sewage Sludge Ordinance (AbfKlärV), only up to five tonnes of dry sewage sludge per hectare can be applied over a period of three years. This corresponds to 25 g of PET per hectare in three years. At first glance, this seems to be a very small amount, but it should be considered that this is only one source of non-biodegradable microplastics, which are also accumulating year after year. Assuming a soil penetration of sewage sludge to a depth of 30 centimeters and a soil density of 1500 kg/m³, the content of PET fibres is about 5 µg/kg.

Research on the effects of microplastics in the soil column are still in the early stages. Song et al. (2019) referred to the exposure of terrestrial snails (*Achatina fulica*) to 0.14 - 0.71 g of PET fibre fragments per kilogram of soil for 28 days. This resulted in approximately 25 to 35 percent reduced food intake and adverse effects on the reproductive capacity of the animals.

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Example of the use of alternative fibre materials in practice: Green Core Fleece Jacket with undyed lyocell fabric on the inside. Photo: VAUDE Sport.

ALTERNATIVE FIBRE MATERIALS

SUSTAINABILITY & PERFORMANCE

Fibres made from recycled polyester and biodegradable raw materials are considered possible alternatives that could help solve the environmental problem of textile microplastics. Their potential, but also ecological and social risks, were analyzed within the framework of TextileMission and essential aspects for the selection of suitable materials were compiled.

A possible approach to reducing microplastic emissions from textiles could be to use fibre materials that a) do not emit any plastic due to the raw material used or b) lead to fewer microplastic emissions when used in the textile. However, in order to ensure that alternative fibre materials do not have other or even more harmful (environmental) effects in other ecological areas, one goal of the project was to analyze them for potential sustainability risks.

SELECTION OF THE FIBRE MATERIALS

Based on selected criteria such as market suitability, scalability, functionality and given the latest developments on the fibre market, recycled polyester (rPET), polylactic acid (PLA) and the regenerated cellulose fibres viscose (CV), modal (CMD) and lyocell (CLY) were included in the project. All these fibres were examined for sustainability risks in relation to their raw material, the production process up to the end-of-life, using scientific literature and expert interviews as a basis. At the same time, the above-mentioned materials were used in various combinations in textile fabrics in order to investigate their emission potential with regard to microplastics. PLA was not considered further in the the project, as it quickly became apparent that the hoped-for advantages in the area of sustainability and the desired performance properties could not be realized. In the following there is a short overview of the main sustainability risks and the performance of the fibres mentioned and an overview of which levers can and should be used for a more sustainable production of the fibres.

POLYESTER WITH HIGHEST MARKET SHARE

The term „polyester“ (PES) generally refers to one of the world‘s most widely used plastics, polyethylene terephthalate (PET). With a market share of around 52 percent (2019), polyester is the most common fibre on the global fibre market and thus plays a major role in the pollution of the environment and oceans by (textile) microplastics.

SUSTAINABILITY RISKS - POLYESTER PRODUCTION

The raw materials for the production of PES are crude oil and natural gas, i.e. fossil, non-renewable resources whose exploration, extraction, transport and further processing entail considerable risks for humans and the environment. These range from socio-ecological risks, the destruction of natural habitats, emissions of various kinds and oil pollution to geopolitical conflict potential. In their totality they can threaten entire communities and ecosystems. Globally, the energy-related greenhouse gases released by oil production alone are estimated to account for approximately two percent. The growing demand for oil is also leading to the development of new extraction methods such as fracking, which is classified as a human and ecotoxicological risk due to the use of chemicals.

Further processing into polyester is associated with a similar number of risks, including high (non-renewable) energy consumption and air emissions (e.g. CO_2, methane, nitrogen oxides, sulfur oxides, carbon monoxides, and hydrocarbons). The latter can be absorbed through the respiratory tract in the event of uncontrolled combustion and become a health hazard. Additives such as UV stabilisers or flame retardants as well as possibly carcinogenic catalysts in the form of heavy metals (e.g. antimony trioxide) are used in production and can enter the environment via wastewater. Such water-based emissions (also for example acids, ammonia) and dissolved solid emissions can cause considerable environmental damage.

In the search for a more sustainable option to polyester made from virgin material (vPET), the recycled variant (rPET) is repeatedly mentioned, referring to the good recyclability of the material, so that rPET now has a market share of around 14 percent of global polyester production (2019). However, the latter claim in particular only applies to a limited extent with regard to use in textiles: the (mechanical) recycling process is in most cases a cascade, as the recycled product is transferred to another, „inferior“ application.

SUSTAINABILITY RISKS IN THE PRODUCTION OF RPET

The material source for recycled polyester are PET bottles, which must have the highest possible material purity. In order to achieve this, sorting by type is important, since more heavily contaminated material requires more intensive cleaning (and thus greater use of water, energy and chemicals). Likewise, if colour consistency is not guaranteed, re-dyeing may be necessary, which again requires energy and chemicals (e.g. chlorine bleach). Another common practice to maintain material purity is to remove bottles from the stream of deposit bottles, thus preventing their actual - and from a sustainability perspective more sensible - reuse as bottles. Another risk can be the increased use of disposable bottles or of new, still unused bottles in order to be able to use the title „recycled material“.

CRITICAL CONDITIONS IN COLLECTION AND SORTING

Depending on the location, both collection and sorting are carried out manually and are often located in the informal sector in developing and emerging countries. Critical working conditions and low wages are a major problem here. While the collection of PET mainly takes place at the local level, the transport to the sorting and production facilities sometimes takes place over global distances and thus represents a further environmental burden. Depending on the type of production up to about one percent solid waste of the total volume can be generated, which is either disposed of in a landfill, used to generate electricity or enters the environment uncontrolled as plastic waste and becomes microplastic later on.

SOCIAL AND ENVIRONMENTAL REQUIREMENTS FOR THE PRODUCTION OF RPET

If the risks exceed a certain level, possible advantages of rPET from a sustainability perspective can be outweighed. Compliance with the following requirement can reduce social and environmental risks associated with rPET and lead to more sustainable production compared to vPET:

1. The origin of the recyclable material should be known and removal from the deposit-bearing bottle stream and post-industrial material should be excluded. Instead, post-consumer material should be used.

2. The use of materials declared as „Ocean Plastic" is good for the image of products, but does not represent the solution. Companies should rather use post-consumer recycled materials on a large scale.

3. The input material has already been recycled (reused or recycled) in its original form as often as possible.

4. The highest possible quality of the input material can prevent increased energy and chemical consumption as well as emissions for processing.

5. Critical chemicals such as antimony should be replaced by tested non-critical alternatives, their use should be regulated, they should be recycled, or at least their disposal should be socially and ecologically safe.

6. Social conditions in waste collection and recycling are known and socially secured by measures. Transport processes are reduced to a minimum.

7. The recycled content in the final product should be as high as possible, as long as the environmental balance for the product does not deteriorate.

8. The recycled goods replace new goods and do not expand the existing product portfolio.

9. Suitable certifications with the highest possible social and ecological standards can cover sections of the production - also specifically for recycled materials.

10. After the end of life of the textile, the collection of the textiles will coordinate a (re)use, so that no textile ends up in the environment.

ADVANTAGES AND DISADVANTAGES OF RPET

Several studies cite energy savings and reduced emissions as the main environmental advantages of rPET over vPET. However, these are partly due to the good recycling structure of the respective countries and vary widely. Differences such as production factors, national regulations or the national energy mix also have an influence, as does the handling of wastewater and production waste. For example, antimony, which is partly used in the production of vPET and which can leak from polyester fibres or bottles to be recycled, may be converted into carcinogenic antimony trioxide at high temperatures and made available for ingestion by living organisms if it enters the environment via wastewater.

From a sustainability perspective, the disposal of textiles made from recycled polyester generally faces the same or very similar challenges as new materials: Worldwide, only up to one percent of textiles are recycled into a product of the same type and quality, including post-consumer and pre-consumer waste from textile production. The rest of the clothing is either landfilled, burned or ends up in the environment and is thus no longer available for further (re) use. Recycling of used synthetic clothing is therefore virtually non-existent. One reason for this is that textiles often contain mixtures of materials. In addition, there are challenges such as the enrichment of the additives (e.g. acetaldehyde reducer or chemical oxygen barriers) or substances migrated into the material. The latter cannot be completely removed in the recycling process and thus restrict a possible other application.

SUSTAINABILITY ASPECTS OF CELLULOSE FIBRES

Celullose fibres (man-made cellulose fibres (MMCF)) are chemical fibres made from regenerated natural materials. Depending on the manufacturing process, individual fibre types are distinguished. Viscose, modal and lyocell were examined in more detail in the project and belong to the group of regenerated cellulose fibres. With an annual production volume of 7.1 million tonnes (2019), cellulose fibres have a market share of 6.4 percent of total fibre production. Viscose is the most significant cellulose fibre, with a market share of around 79 percent of all MMCF, with lyocell in third place at around four percent and modal behind at 2.8 percent.

The primary raw material for production of cellulose fibres is pulp. This can be obtained from almost any plant, but in most cases trees are used. Commonly used wood species are beech, eucalyptus, spruce, pine or bamboo. The type of wood used depends on the end product, the production site and the manufacturer. Beech wood is primarily used for viscose and modal and eucalyptus for lyocell. Studies on the sustainability of the three fibres compared to synthetic fibres (mainly polyester) and cotton show potential savings in the use of renewable energies and in the reduction of greenhouse gas emissions. In addition, there are advantages in connection with a possible closed-loop recycling of the chemicals used, as well as the additional end-of-life option of biodegradability. However, the individual advantages can vary greatly between fibre types and thus have an influence on environmental compatibility.

THE CULTIVATION OF RAW MATERIALS AS AN ENVIRONMENTAL RISK

Forests perform many essential functions: They store carbon dioxide and help control climate change, and they are home to a large number of species (endangered and protected). Deforestation and logging reduce this capacity and can impact the livelihoods of indigenous peoples and entire ecosystems. For example, it is estimated that for viscose production alone, approximately 120 million trees will be felled, some of which come from endangered and old-growth forests, such as those in Indonesia and Canada.

The extraction of raw materials can be accompanied by clear-cutting, thinning, removal of natural (soil) vegetation or the use of agrochemicals. Soil erosion and the deterioration of water quality due to organic material resulting from debarking and transport are further risks that need to be considered.

The use of eucalyptus wood carries the risk that the species, due to its fast growth, adaptability and wood quality, is now cultivated in more than 90 countries and can thus displace native species. Brazil is now promoting genetically modified eucalyptus species as they have been approved for commercial cultivation since 2015. In addition, the essential oils in eucalyptus can increase the risk of forest fires.

Beech trees are usually sourced from domestic areas. Time-consuming forestry work and demanding processing can be critical here, so that close cooperation between the interlinked economic sectors (from forestry to the plastics industry) is essential for long-term sustainable use.

SOCIAL AND ENVIRONMENTAL REQUIREMENTS FOR THE PRODUCTION OF VISCOSE, MODAL AND LYOCELL

In order to ensure possible advantages of viscose, modal and lyocell from a sustainability perspective, certain requirements must be met.

1. The raw material wood is sourced exclusively from certified sustainable forestry. The highest standard should serve as a guide.

2. In the best case, the pulp used is obtained as a by-product, so that cascade utilization is implemented.

3. Working conditions are based at least on the standards of the International Labor Organization (ILO).

4. Chemicals used (including CS_2, H_2S, $ZnSO_4$) are kept in a closed loop and do not enter the environment. Recovery plants or other re-uses can be a solution here. The same applies to waste and air emissions of any kind.

5. The location of production is chosen carefully and regional and national conditions are known, as environmental balances can vary greatly.

6. Production processes are always based on the EU BAT standard (best available technology) or - if not available - on the most advanced standards in the industry.

7. Despite possible biodegradability, it must be ensured after the use phase that the textiles do not end up in the environment or that emissions (unused) escape. Reuse or recycling of the textile (ideally from post-consumer materials) is the aim, provided that the environmental balance sheet permits this.

In principle, when wood is used as a raw material, the question must be asked as to what the most sustainable use can look like, since the energy and material use can be in competition with each other. The potential for cascade use must also be considered in order to increase raw material productivity where appropriate.

SOCIAL AND ENVIRONMENTAL RISKS

In the context of viscose production, the most important environmental and social aspects are air and water pollution, solid waste, energy consumption and worker health and safety. In principle, viscose has the potential to be produced in a sustainable way, but in many cases the appropriate practices are not implemented.

The production of lyocell differs in some aspects and has to be considered separately. Both pulp production and fibre production can result in emissions to air and water. Sulfurdioxide, nitrogen oxides, dust and carbon monoxide as well as chlorine compounds used during the bleaching process (pulp or fibre) can be released into the atmosphere. Emissions to water are dominated by organic and inorganic substances (sodium sulfate and zinc in the case of viscose) and wastewater from the bleaching plant. Chlorine bleach, for example, can lead to the emission of dioxin, which is classified as a persistent organic pollutant and highly toxic to humans and the environment. The same applies to chemicals such as carbon disulfide (CS_2) or zinc sulfate ($ZnSO_4$). Here, practices differ greatly, depending on the fibre and manufacturer.

For example, in the lyocell production process, the pulp can be dissolved using the organic solvent N-methylmorpholine-N-oxide (NMMO) without any further chemical additions or modifications and then converted into pulp in a closed loop. > 99 percent can be recovered and returned to the production process. The lyocell process is therefore more environmentally friendly than the viscose and modal process, if appropriate measures are implemented.

With regard to end-of-life, textiles based on cellulose fibres are basically subject o the same sustainability risks as synthetic ones, which is partly due to disposal via household waste or bundled collection. However, cellulose fibres have another end-of-life option: biodegradability. Viscose, modal and lyocell are proven to be biodegradable in soil, compost, and fresh and sea water. However, the degradation times of both fibre types depend on the environmental conditions and the manufacturer.

PERFORMANCE OF POLYESTER AND CELLULOSE

Table 1 compares selected properties of cellulose fibres with those of polyester, using viscose as an example. In addition, the properties of lyocell are listed in order to make the comparability between viscose and lyocell clear and also to establish the reference to the fibres used in the project: Cellulose fibre (lyocell) and rPET.

Polyester as the most frequently used fibre material is characterised by a high durability, is easy to process and easy to clean. One of the reasons for this is that polyester absorbs very little moisture and is very hard-wearing due to its high (tear) strength and low shrinkage. The reduced ability of polyester to absorb bacteria means that the bacteria remain on the surface and can lead to stronger odour formation.

	Regenerated cellulose fibres[1] (viscose, CV)	**Lyocell[2] (LYC)**	**Polyester[1] (PES)**
Density (g/cm³)	1,52	1,50	1,37
Moisture absorption at 21°C, 65% rH (%)	13	11	0,4
Moisture retention (%)	103	-	4
Strenght (cN/dtex)	25	-	33
Tear resistance (cN/dtex)	2,7	3,6-4,0	4,5
Elasticity at 2% stretch (%)	83	-	94
Shrink at 95°C water (%)	5	-	1
Resistance to thermal treatment, hot air 120°C (%)	30	-	95
Biological stability	Not resistant to bacteria	Not resistant to bacteria	Very good

Table 1: Comparison of selected performance values of regenerated cellulose fibers and fibers made from rPET. Sources: [Denkendorf Fiber Chart (1986)][1] and Lenzing Fibers[2] (2021)].

In terms of feel, polyester appears artificial due to its synthetic origin. For recycled polyester, the listed properties are comparable due to the identical polymer base. Differences can arise due to the recycling process used, which can affect the strength of the fibre.

Due to its ease of use, both in manufacturing and maintenance, polyester has become established for use in fleece products in recent years. However, more and more manufacturers are also venturing into products made from natural fibres (e.g. cotton) or cellulose fibres. Compared to polyester, lyocell, for example, absorbs a lot of moisture and is not as hard-wearing with a lower strength and increased shrinkage. However, the fibre feels particularly soft and natural on the skin. Thus, the cellulose fibre has a moisture-regulating effect and absorbs odours less strongly because to its natural base. Due to this natural basis and the resulting lack of resistance to bacteria, the cellulose fibre can also be described as a biodegradable material in various habitats (see page 23).

SUMMARY AND RECOMMENDATIONS FOR ACTION

Both recycled PET and regenerated cellulose fibres have the potential to be a more sustainable alternative to virgin polyester (vPET) in terms of their raw material extraction, production and disposal. However, this strongly depends on the specific conditions mentioned, such as cultivation and production site, mode of operation, energy mix and waste management. Putting these findings in the context of possible textile microplastic emissions, recycled polyester can achieve sustainability advantages in production compared to virgin polyester, but it still contributes to the microplastic problem. Regenerated cellulose fibres, on the other hand, can achieve sustainability benefits in production and also offer the possibility of reducing microplastic emissions to the environment due to their basic biodegradability.

It should be noted that this statement only applies to the pure fibres. Fibres are subject to a multitude of processing and finishing steps that have an influence on their behaviour in the environment. For

GUIDE TO ASSESSING THE SUSTAINABILITY OF FIBRES

Important aspects in the assessment of sustainability include the underlying raw material, the cultivation region, the cultivation methods, the technologies and energy sources used, transport, production and processing procedures, the use phase and end-of-life handling. The following aspects can be helpful in assessing the sustainability of fibres.

1. The production facilities and operating methods are known and are subject to strict regulations and regular audits. Likewise, local conditions are known - also in the cultivation of raw materials. Traceability can be a suitable tool here.

2. Important levers for more sustainable production are increased and more efficient use of renewable energies, optimized collection systems for used clothing, improved product design, shortening of transport routes and minimization of waste.

3. All chemicals used are known and evaluated for toxicological and ecological aspects. Their use is kept to a minimum and chemicals are kept in circulation for as long as possible. They are not released into the environment, but are disposed of properly.

4. Textiles are designed for long reusability and good and frequent recyclability (into similar products).

5. Selected certifications with high requirements and regular audits can cover certain standards in parts of the production. So far, no certification covers the entire textile chain. National and regional certifications or initiatives can be considered in addition.

6. No material declared as „ocean plastic" or „marine litter" is used in recycled products, but verifiably post-consumer material is used.

7. Fibres and textiles based on natural raw materials do not necessarily have to be a more sustainable alternative, but initially have other risks, which are related, for example, to the cultivation of the raw materials. In addition to general agro-ecological risks, concrete raw material-based risks, country- and region-specific risks, and possibly supply chain-specific risks must also be taken into account. If the above criteria are met, an environmental advantage can be achieved.

8. In the case of biobased alternatives, it should be noted that production has so far often been focused on local markets. Strong growth can cause international flows of goods and, as a result, hitherto unknown social and environmental impacts.

9. From a sustainability perspective, the question of the most sensible use of renewable raw materials should be asked. Often, the use of energy and materials are in competition with each other. At best, both can be combined through cascade use or the use of by-products, and savings in greenhouse gas emissions and energy consumption can be achieved.

10. The end of life of textiles is usually associated with the same risks, regardless of their material. A suitable collection and sorting system should therefore be applied in order to implement appropriate sustainable end-of-life options.

this reason, a realistic sustainability assessment that encompasses as many relevant aspects as possible can only be made individually for the specific end product and across the entire textile chain. Fibres alone are only an intermediate product. The design and finishing of the textile have a major impact on sustainability and environmental impact.

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How to produce fleece material in such a way that it emits as little microplastic as possible was researched at Niederrhein University of Applied Sciences. Photo: Susanne Küppers.

MATERIAL DEVELOPMENT

INNOVATIVE DESIGNS: YARN AND MACHINE PARAMETERS

Alternative manufacturing methods for surface constructions are one way of reducing the input of fibrous microplastics into the environment. The scientists at Niederrhein University of Applied Sciences have investigated which processes are the most promising. The focus was on fleece articles that undergo a highly stressful mechanical finishing process in order to be particularly voluminous and warming with a low material weight.

Fleece is based on a two-ply fabric construction, typically produced on circular knitting machines. The manufacturing process is also referred to as reverse plating and uses two yarns in three layers: a pile yarn, which is on the outside on both fabric sides and a ground yarn, which forms the base construction in the middle layer (see Fig. 1). The voluminous surface is mainly created by the knitting construction in combination with mechanical finishing processes, which destroy the surface and lead to a fibre loss of up to 20 percent already during production.

The manufacture of a fleece consists of a sequence of different production processes, which can be varied according to the desired result and requirement profile (Fig. 2). In this type of textile finishing, the textiles are first processed with metal hooks arranged on rotating raising rollers (Fig. 1 C). This breaks up the pile yarns and yarn loops of the knitted fabrics. The pile yarn is converted into a fibre pile. This pile can then be shortened by shearing to a desired uniform fibre length. Detached fibre fragments are removed from the textile product by machine-integrated suction devices.

The findings of the washing tests with commercially available products (see article starting on page 13) were used to optimize textiles for the same purpose. Individual steps in the value chain were considered separately in order to reduce the risk of subsequent emissions of microplastics in the use and care of the end product..

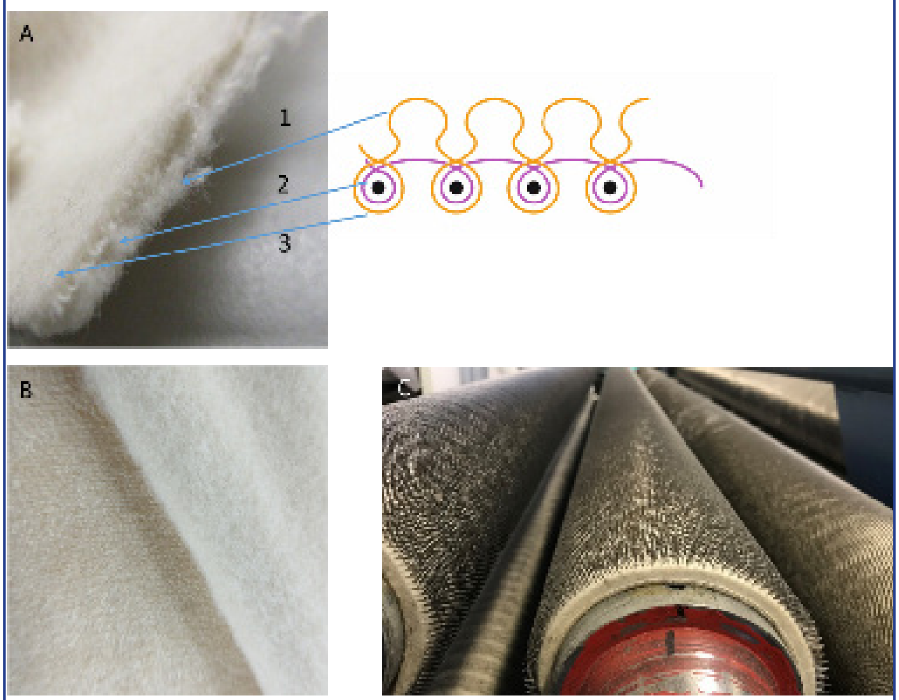

Fig. 1: Layered construction structure for a fleece fabric. Yarn distribution within the reverse plating: Fig. A, 1+3=pole yarn, outside on right and left fabric side, here napped on both sides, Fig. B: Ground yarn (inside), largely undamaged in the napping process), example of a fleece material, representation of the napping rollers (C).
Illustrations: Niederrhein University of Applied Sciences

MATERIAL DEVELOPMENT STRATEGIES

PES fleece was chosen as the focus for material development due to its properties and strong market presence. Two strategies were chosen to reduce the emission of non-biodegradable microplastics:

First: The optimization of fleece materials made from 100 percent PES (in pile and base yarn). In addition to classic virgin PES types, polyester fibres made from recycled PES (rPET) were also investigated.

Second: The combination of biodegradable, cellulosic materials in the pile yarn on the outer sides, with polyester in the base yarn of the middle layer for fabric stability.

In the selection of cellulosic fibres, lyocell and modal were chosen as sustainable, regenerated fibres, which are more environmentally friendly than cotton fibres, which in turn are are criticized as agricultural products due to high water consumption and pesticide use in cultivation. Lyocell and modal consist of the same plant polymer as cotton, cellulose, and therefore exhibit a similar hygroscopic behaviour to cotton, i.e. they absorb moisture. In addition, the fibres are biodegradable. This means that released fibres can be degraded to water and CO2 over time and depending on environmental conditions. However, the good moisture absorption behaviour is not only positive: textiles made of lyocell or modal do not exhibit any barrier effect against water, i.e. in terms of weather protection performance, they are inferior to synthetic polyester fibres..

OPTIMISATION APPROACHES IN THE PRODUCTION PROCESS

In order to achieve the greatest possible reduction in the emission of microplastics, each step in the process chain was considered and investigated separately: Yarns: Yarn types commonly used in trade and production were investigated: PES yarns were used as continuous filaments with different filament counts and the cellulosic yarns in the form of lyocell and modal yarns as staple fibre yarns. For the latter, different spinning processes (ring spinning process and compact spinning process) with the same yarn count (Nm 40/1) and the same twist (664 T/m) were chosen.

Furthermore, specially cross-linked lyocell fibres were considered. These prevent fibrillation in the dyeing and finishing process and thus surface hairiness and increased pilling tendency in use.

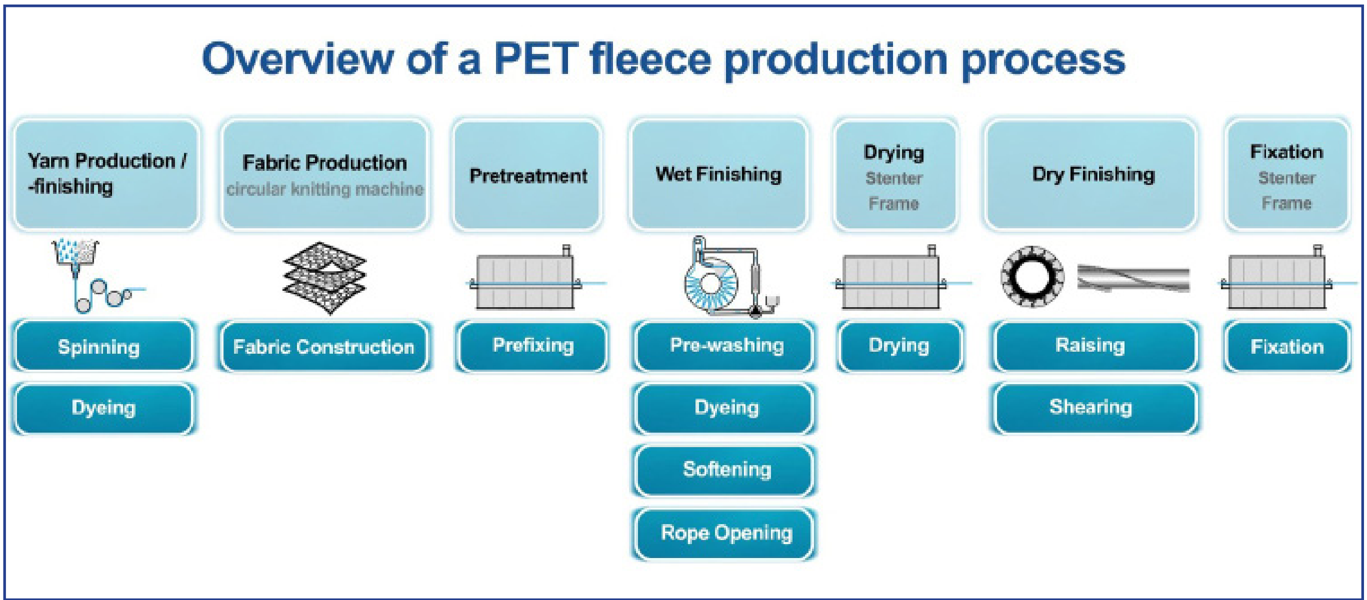

Fig 2: Overview of a typical production process of fleece material. Graphic: Niederrhein University of Applied Sciences

The modal fibre yarn and a polyester filament yarn were also used as exemplary spun-dyed yarns, i.e. they were already dyed during fibre production. The colour pigments were added to the spinning mass. This facilitated the differentiated observation of the fibre emission, and a separate exhaust dyeing process could be omitted.

Of all the yarns used as pile yarns in the fleece, the technological properties of maximum tensile strength, elongation and loop strength were investigated. Furthermore, they were processed into single-thread test knits on which the dry and wet abrasion resistance and the fibre particle emission in the laboratory laundry were determined (the materials were purchased from or provided by various European fibre and yarn manufacturers, such as Lenzing AG, TWD Fibers GmbH and Trevira GmbH). Polylactic acid (PLA) and other bio-based plastics were excluded because they behave like conventional plastics in the environment, recycling possibilities are lacking, the very hard handle of the material does not fit the requirement profile of the desired product and is very expensive.

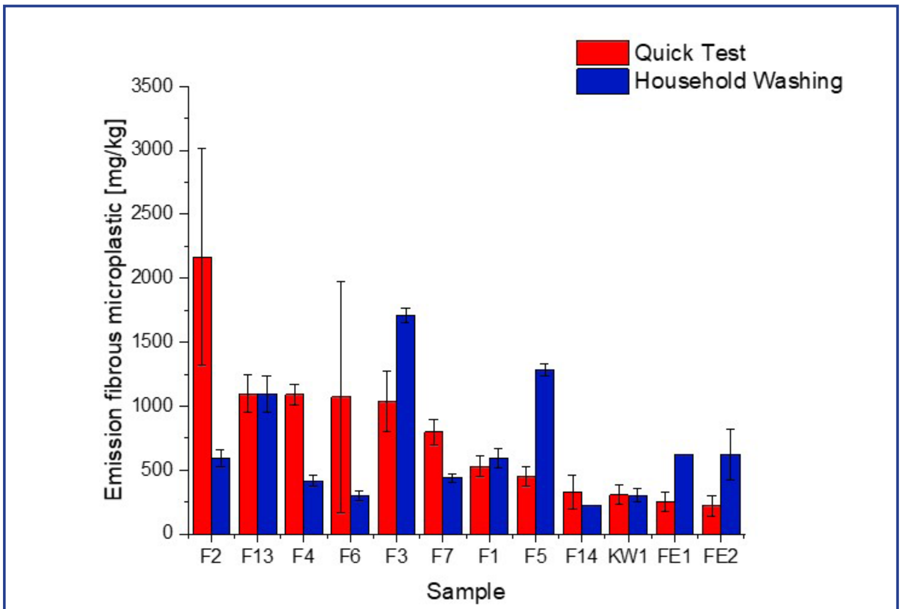

Fig. 3: Comparative studies of lab-scale washes (quick test) and household washes (from high output in lab-scale to low output) | F = fleece from the market, FE = fleece own development, KW = warp knitted fabric raised.
Source: Niederrhein University of Applied Sciences

Fabric construction: For the material development on an industrial scale, 38 knitted fabrics in gauge E24 were produced on a plush circular knitting machine of type MPU 1.6 from Mayer Cie. by varying the yarn selection and combination as well as the process parameters yarn tension, sinking depth and fabric take-down. In addition to various 100 percent PES fabric constructions (in both pile and ground yarns), combinations of PES yarns in the ground yarn were also combined with cellulosic materials in the pile yarn (cellulose fibre content 68 percent and polyester fibre content 32 percent).

Finishing: In addition, the coloration as well as the chemical and mechanical finishing were varied in order to adapt the textiles to their function as outdoor articles. In the case of the fleece materials at the center of this study, it was only at this point in the textile processing that the voluminous, functional, i.e. thermally insulating character of the fabric

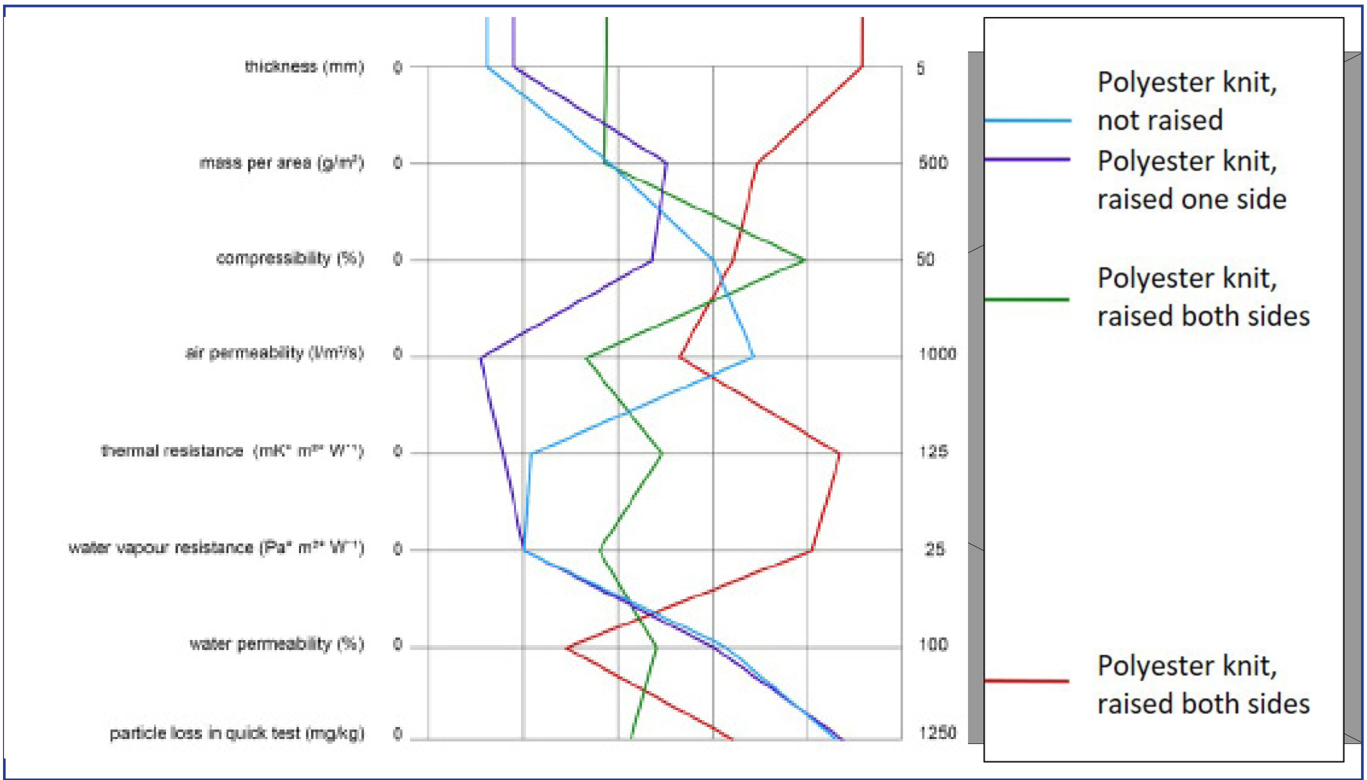

Fig. 4: Illustration of the performance values and properties of different materials in comparison to microplastic emission. Source: Niederrhein University of Applied Sciences

was formed. For this purpose, the most effective mechanical finishing process (raising and/or shearing) was worked out and finally implemented. The 100 percent PES samples were subjected to technological and physical tests to determine the suitability of the material for outdoor use (see Fig. 4).

RESULTS

Yarns: Already during the knitting process, it could be seen that staple fibre yarns made of lyocell fibres caused a high fibre emission, which settled on the various parts of the knitting machine. Yarns made from modal fibres showed less fibre emission or fibre abrasion. Knitted fabrics with ring yarn in the pile showed a significantly higher emission than those with compact yarns. Yarns with low fibrillation finish showed significantly lower discharge values than standard yarns. In the washing test, the knitted fabrics with cellulosic content released considerably more fibre fragments than the materials made from PES filament yarns.

As part of the in-house development, it was found that a higher number of filaments in the pile yarn (100 dtex with 72 filaments and 110 dtex with 36 filaments), with otherwise constant parameters in the manufacturing process, results in a softer and more pleasant touch. The raising energy can be lower.

Knitted fabrics made from yarns of the same yarn count with finer individual fibres show a higher fibre output in laboratory washing tests using a quick test. This effect cannot be observed in washing tests on household washing machines, and in some cases opposite results can be observed. The quantitative comparisons of the weights of discharged fibre quantities in the filter residue do not yet allow any conclusions to be drawn about the type of fibre fragments; finer fibres will inevitably lead to finer fibre fragments. Investigations on a laboratory and domestic scale generally show considerable differences, as Fig. 3 shows.

As the investigations carried out here currently stand, the quick test must not be used alone to derive the behaviour of a textile material in the household laundry. A significant difference between recycled polyester and virgin polyester could not be determined.

A special position among the cellulosic materials is occupied by the spinneret-dyed black modal yarn. In the various yarn tests and on both knitting machines (laboratory and industrial scale), significantly less fibre emission can be seen than with the other cellulosic yarns. Thus, there are already various factors connected to the yarn that have a significant influence on the overall fibre output in the production process.

Fabric construction: The properties of 100 percent polyester knits with different appearance and material character (raised on one side, raised on both sides, without mechanical treatment) were analysed. The results are summarised in Figure 4. The different properties depend, among other things, strongly on the finishing process.

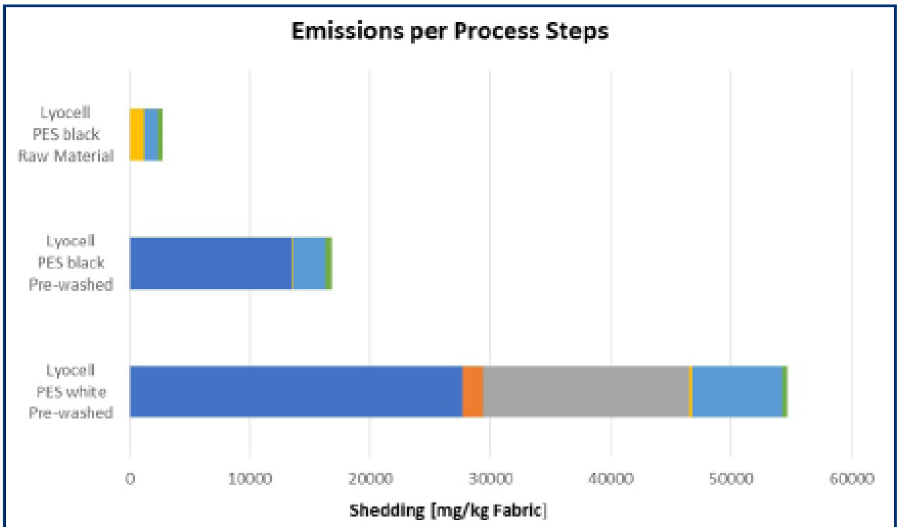

Fig. 5: Overview of particle emission related to individual washing and dyeing steps in textile finishing. Source: Niederrhein University of Applied Sciences

This also has an effect on the fibre output in the laboratory washing test. Basically, any change in the knitting and mechanical finishing parameters can not only change the fibre emission, but also the functionality or performance of the fabric. A correlation between certain functionalities, such as air permeability or the like and the fibre emission could not be determined. Various knitted fabrics were tested for fibre emission directly after the knitting process using the laboratory washing test. It was found that already at this stage of the process there is a clear fibre emission - partly corresponding to that of a finished product.

Finishing: In order to get an impression of the particle emission during finishing (washing and dyeing processes in fabric production), random samples were taken from the process water of the textile finishing for the cellulosic blended materials. These were analysed for microplastics and indicated that fibrous microplastics are already introduced into the hydrospheres in the textile process chain, before household washing (Fig. 5). When buffing the cellulosic materials, the entire finishing process had to be substantially changed, since the materials responded differently to mechanical processing.

However, it was basically possible to produce a soft, voluminous material that is very similar to PES fleece in terms of the overall fabric appearance and feel and has a significantly lower PES fibre emission than 100 percent PES yarns.

CONCLUSIONS FROM THE RESULTS

The emission values of different materials (raised on one side/both sides) in different production stages (after knitting, after dyeing and in the final fabric) show that microplastics are released at each stage. The knitting process itself already seems to cause considerable mechanical stress due to the deflection of the yarns in the thread guide and leaves a lot of fibre material on the knitting machine and in the fabric. The analysis of the individual wet finishing steps showed that during the water-based finishing processes, a significantly larger amount of fibrous microplastic is discharged from the textiles overall than in the case of household washing. This aspect must be taken into account, as the corresponding production facilities are often located in countries where the wastewater system is significantly less developed than in Germany..

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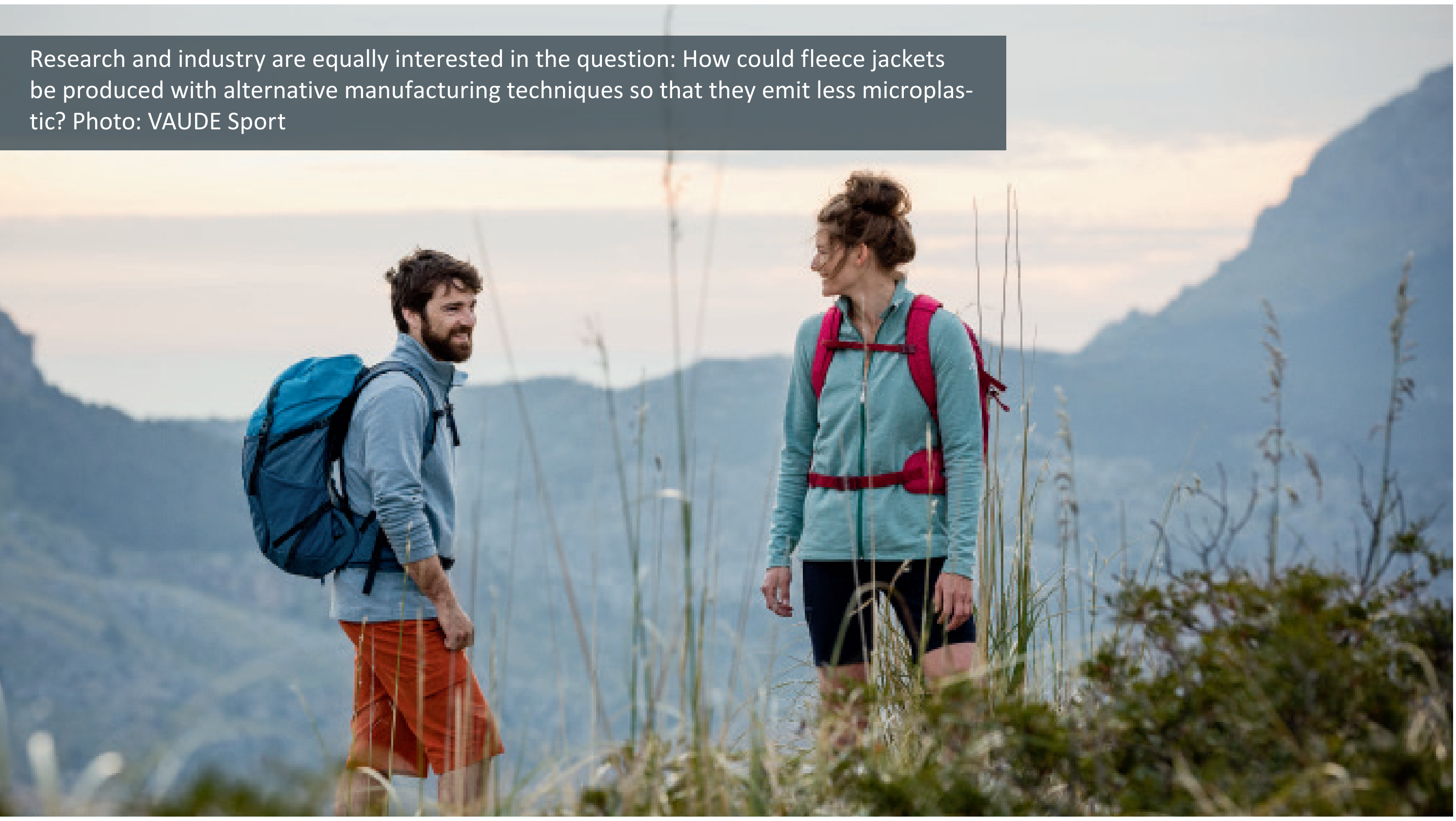

Research and industry are equally interested in the question: How could fleece jackets be produced with alternative manufacturing techniques so that they emit less microplastic? Photo: VAUDE Sport

GARMENT DEVELOPMENT

ALTERNATIVE CUTTING AND JOINING TECHNIQUES

During the course of TextileMission, Niederrhein University of Applied Sciences was able to identify the manufacturing of the finished clothing textile, in addition to the household laundry and the production of the fabric, as a further important factor for the amount of microplastic emission. As a result, various practical trials with alternative cutting and joining processes were carried out.

Due to the high fibre emission in the first wash and during drying (see article starting on page 13), it can be assumed that the manufacturing process itself, in particular cutting and joining, as well as the handling of the textiles in production (cutting-making-trimming - CMT), causes contamination of the textiles with microparticles. A further indication of such contamination could be the fact that not only fleece articles but also smooth, mechanically untreated materials strongly emit during the first wash. This was reason enough to examine the CMT production processes - starting from the textile fabric to the final garment - in more detail.

The basis for the manufacturing process of an item of clothing, is the creation of the 2D pattern pieces that convert the desired design to a production ready pattern.

After the creation of the patterns and laying instructions, the first production step is to form a lay (lay out and stack of single layers for efficient cutting) and then to cut the lay (divide/separate the textile pieces). Then the multi-layer cut parts are separated again, sorted, attached if necessary, and then assembled in the sewing department to a final product.

MECHANICAL AND THERMIC SEPARATION PROCESSES

All separating processes remove the material cohesion at the processing point and destroy the material locally. The open cutting edge created in this way can therefore already leak fibres during the manufacturing process, while the product is being used, or being laundered. Regarding the physical effect of separating, cutting technologies can be differentiated:

- mechanical cutting with knives, punching, shearing, high pressure water jet;
- thermal cutting by means of laser beam;
- thermal-mechanical cutting by means of ultrasonic cutting (Fig. 1).

These technologies are used in CNC-controlled automatic cutting machines (cutters) or manually operated machines. In series production for clothing products, automatic high-ply cutters (up to 80 mm of compressed material can be cut) with a vertically positioned oscillating knife are the current standard for multi-layer cutting. The number of layers depends on the type of material and the size of the job. Experience shows that by this and other mechanical cutting processes, fibres can very easily become detached at the edge, and fibres often become "hooked" between the individual layers. One advantage of thermal cutting is that it is possibile to seal the edge of synthetic materials by melting the edge fibres..

INFORMATION ON THE TEXTILE MARKET

Due to the production volumes and labour-intensive manufacturing the production of textiles and clothing mainly takes place in series or mass production in Asia, as a bought-in product in full-package supply or also OEM original equipment manufacturing or in the system of passive contract processing. In 2019, Germany imported textiles and clothing from China with a total value of approximately 10.6 billion euros, of which more than three quarters were apparel (statista.com, 03/2020).

JOINING PROCESSES

Joining is the bringing together of two or more parts. Joining processes for textiles are sewing, bonding, welding and riveting. The sewing technique is a classic and at the same time a very universal and versatile process, both in terms of the materials that can be processed and in terms of the process parameters (variety of stitch types, sewing threads that can be used, seam types, etc.), and was used in the products studied in the TextileMission project.
During textile welding processes the thermoplastic materials (e.g. polyester, PES) are plastified by hot air, contact heat, ultrasonic or laser technology and joined, often by using pressure. As part of the TextileMission project, the versatile continuous ultrasonic welding technology was identified as an alternative joining technique to conventional sewing. This technique is considered to be a sustainable, low-maintenance, single-variety and "clean" process. Additional materials such as sewing threads are not required, and there are no wearing parts such as sewing needles. In addition, there are no perforations of the material by the needle and it is possible to fuse the cut edges at the same time as joining. This thermally seals the edges and thus minimizes possible fibre leakage, as expected.

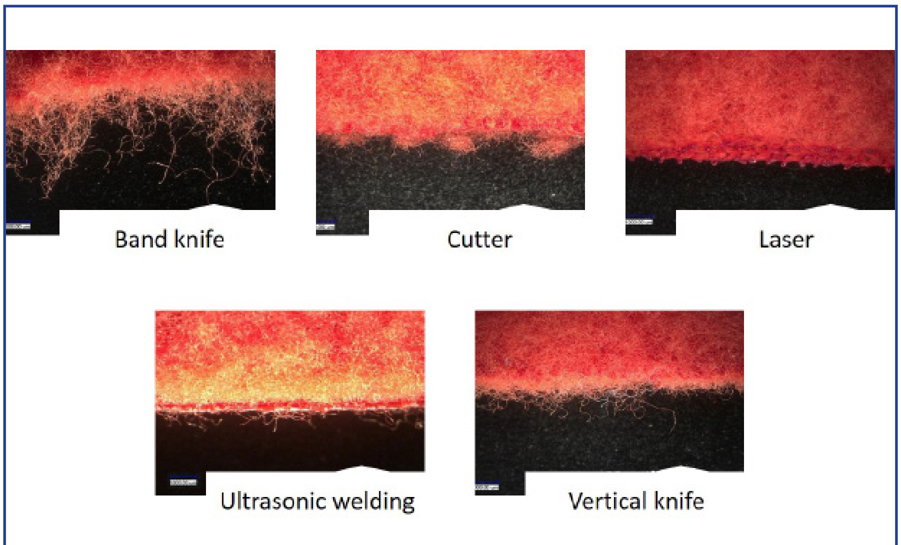

Fig. 1: Comparison of edges of a fleece material produced by different separation processes. Source: Hochschule Niederrhein, Maya Breuer

PRACTICAL TESTS

In the first step of investigation, extensive cutting and seaming samples were prepared with 100 percent PES fleece fabrics in order to compare the different technologies on a laboratory scale with up to ten washing cycles (the cellulosic material blends were initially not included in the test due to other processing steps): The cutting and joining processes are influencing factors for fibre emission.

The best results by far for cutting, with around 70 percent less microplastic emission, are achieved by single-layer cutting with a laser cutter (compared to mechanical multilayer cutting). Observation of the samples under the optical microscope confirms the fusion of the cut edges and thus their thermal sealing (see Fig. 1). The fibre emission was lowest for the sealed or concealed edge processing compared to the conventionally sewn and also compared to the pure material surface.

ZERO WASTE PATTERN FOR TEST MONITOR

For a differentiated investigation of the influence of the joining processes, a zero-waste-pattern was developed for a test monitor, which was based on the product jacket, but reduced to a minimum and could be used without additional materials (pockets, closures, linings or similar) for the household washes (Fig. 2). In order to compare the laboratory monitors with those of an industrial production, in cooperation with VAUDE and LTP Garment (Lithuania), several materials made of 100 percent PES (in-house development and industrial goods) were selected and made up in parallel in the industrial production and in the laboratories of the university. All variants were examined for microplastic discharge after household washing and drying.

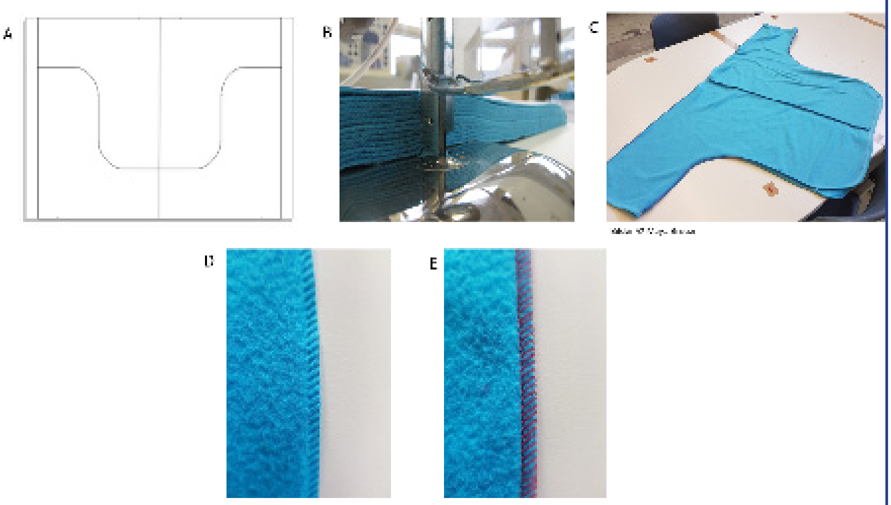

Fig. 2: Cutting pattern developed at Hochschule Niederrhein (HSNR) for zero-waste monitor (A), multi-layer cut with the vertical/sharp knife (B), final zero-waste monitor (C), welded seam (D), sewn seam (E). Source: Maya Breuer

It was found that the fibre loss was highest for the externally produced monitors. Due to the real production conditions on site, cross-contamination seems to have occurred on the fabric, leading to higher values in the washing tests. In addition, the monitors cut to size at Niederrhein University of Applied Sciences were joined both conventionally by sewing and alternatively by ultrasonic welding (Fig. 2). In the case of these monitors, no major difference in fibre emission was found in the household laundry when comparing the joining processes.

SUMMARY

In the laboratory washing test, the welded edges and seams showed better emission results than the conventionally cut and joined samples. This was partially confirmed in the household wash. This can obviously be attributed to the mechanics in the wash, as a result of which the welded and so thermally sealed edges in the wash are partially broken open again. Optimization attempts should be made in this regard. The aim is to reduce the overall workload as much as possible and to keep the cost of the edge processing low in order to ensure feasibility in terms of costs. When it comes to joining, the edge processing methods with a high coverage of the cut edge show the best results overall. Here, further seam designs and parameters should be evaluated to find the best solution for a material and product.

The use of thermal cutting processes (laser) and additional edge protection with bonded tapes are further possible optimization approaches. Overall, however, the fibre emission of the monitors produced in industry was consistently greater than that of the monitors produced in the university laboratory, which basically confirms a contamination due to the production environment and handling.

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GLOSSARY

µ-FTIR	µ-Fourier transform infrared spectrometry
Cellulosic fibres	Fibres made from the raw material cellulose. These can occur naturally (e.g. cotton) or be synthetically produced (e.g. viscose)
Fibrous microplastic	Smallest fibres and fibre fragments from synthetic textiles
Filament	International term for fibres of practically unlimited length. Filaments are also referred to as continuous fibres. A filament is defined as a fibre of at least 1000 m in length
Filament yarn	Yarns made from filaments
Filament count	Number of filaments in a yarn
Yarn count	Indication of what mass a yarn of a certain length has, there are different units: e.g. Nm 40/1 means 40 m of the yarn weigh 1 g. e.g. 100 dtex means 10.000 m of the yarn weigh 100g
Finishing	Processes for upgrading the fabric to achieve certain properties and functions; mechanical finishing: treatment of the textile with machines, e.g. for roughening or shearing; chemical finishing: treatment of the textile with chemicals, e.g. dyeing, anti-pill finish incl. washing steps, soil-repellent finish
HSNR	Hochschule Niederrhein - University of Applied Sciences
Joining	Bringing together two or more workpieces to form a solid bond
Microplastics	Plastic particles with a size < 5 mm
Monitors / Laboratory Monitors	Garment for testing, eg. a jacket without additional materials (fasteners, linings or similar), which can be used for differentiated investigation of the influence of joining processes on microplastics emission in the simulation of household washes

PES	Polyester (for textiles usually made of polyethylene terephthalate)
PET	Polyethylene terephthalat
Pilling	Nodule formation on the surface of textiles
Regenerated fibres	Fibres produced from natural, renewable raw materials via chemical processes
Ring yarn	Yarn produced by the ring spinning process
Rotation	Yarn parameters, e.g. 664 T/m means: 664 twists are applied to one meter of the yarn
rPET	Recycled PET
Staple fibre	Natural or man-made fibre of limited length; long staple fibres (shorter than 600 mm), medium staple fibres (shorter than 60 mm) and short staple fibres (shorter than 40 mm)
Synthetic fibres	Fibres from the raw materials coal, natural gas and crude oil
TED-GC/MS	Thermo-Extraction-Desorption-Gas Chromatography/ Mass Spectroscopy
VirginPET	new PET based on petroleum or natural gas
Zero-Waste-Pattern	Design technique that eliminates fabric waste and other textile waste already during the design and during the cut construction process

OUR PARTNERS

PROJECT PARTNER

FEDERATION OF GERMAN SPORTING GOODS INDUSTRY

BSI - **Bundesverband der Deutschen Sportartikel-Industrie e.V.** is the business association of German sporting goods manufacturers, importers and wholesalers founded in 1910. The BSI currently has around 150 member companies. In addition to large international companies, over 80% are small and medium-sized companies that are market leaders in their sports segments. The members of the German Sporting Goods Industry Association generate annual sales of around 35 billion euros.

HOCHSCHULE NIEDERRHEIN - UNIVERSITY OF APPLIED SCIENCES

Hochschule Niederrhein - University of Applied Sciences is one of the strongest research universities in NRW. At the Research Institute for Textiles and Clothing (FTB), which is affiliated with the Department of Textile and Clothing Technology with over 2000 students, 23 professors and 31 scientific employees work on scientific, industrial and publicly funded projects together with over 60 students. The entire textile value-added chain from yarn production to surface can be mapped. The institute focuses on the chemical and constructive functionalization of textiles, smart textiles, product development and sustainable manufacturing.

TU DRESDEN - INSTITUTE OF WATER CHEMISTRY

Water and environmental protection is the overriding goal of the research and teaching activities at the **Institute of Water Chemistry.** The occurrence, properties and (environmental) behaviour of chemicals and materials that are predominantly introduced anthropogenically into the water cycle, such as pharmaceuticals, microplastic particles or pesticides, are investigated. In addition, research is being conducted into concepts for drinking water and wastewater treatment in order to safely and efficiently remove such trace substances from water.

VAUDE SPORT GMBH & CO. KG

VAUDE offers functional and innovative products for mountain and bike athletes. As a sustainably innovative outdoor outfitter, VAUDE contributes to a world worth living in, so that tomorrow's people can enjoy nature with a clear conscience. In doing so, the family-owned company sets ecological and social standards worldwide. VAUDE stands for environmentally friendly products from fair production. At its headquarters in Tettnang in southern Germany, the company employs around 500 people.

WWF GERMANY

WWF Germany is part of the international environmental protection organization World Wide Fund For Nature (WWF). For over 50 years, the WWF network has been working around the globe to stop environmental destruction and shape a future in which people and nature live in harmony. In more than 100 national and international projects, WWF Germany is currently working to preserve biodiversity and our natural livelihoods. More than 500,000 sponsors support the organization in this endeavor.

ASSOCIATED PARTNERS

ADIDAS AG

adidas is one of the world's leading suppliers in the sporting goods industry with its core brand adidas. Headquartered in Herzogenaurach, Germany, the company employs more than 60,000 people worldwide and generated sales of €23.6 billion in 2019.

HENKEL AG & CO. KG AA

Henkel has a balanced and diversified portfolio worldwide. With its strong brands, innovations and technologies, the company holds leading market positions in both the industrial and consumer businesses: Henkel Adhesive Technologies, for example, is the global market leader in adhesives. With its Laundry & Home Care and Beauty Care business sectors, the company is also a leader in many markets and categories. In the fiscal year 2020, Henkel generated sales of 19.25 billion euros and adjusted operating profits of 2.6 billion euros.

MIELE & CIE. KG

Miele is the world's leading supplier of premium domestic appliances for cooking, baking, steam cooking, refrigeration/freezing, coffee preparation, dishwashing, laundry and floorcare. In addition, there are dishwashers, washing machines and tumble dryers for commercial use as well as washer-disinfectors and sterilisers for medical facilities and laboratories ("Miele Professional"). Founded in 1899, the company has eight production sites in Germany and one plant each in Austria, the Czech Republic, China and Romania. Sales in the fiscal year 2020 amounted to around EUR 4.5 billion.

POLARTEC LLC

Polartec, LLC is a premium manufacturer of innovative textile solutions. Since the company invented synthetic fleece in 1981, Polartec engineers have been continuously working on new fabric technologies that continue to push previous boundaries. Today, Polartec delivers the world's most advanced fabric innovations. Polartec® offers a wide range of functional fabrics, from lightweight baselayers to thermal insulating fabrics and fabrics for extreme weather conditions. The fabrics are used worldwide by leading apparel manufacturers, the US military, workwear brands and partners in the upholstery industry to create high-performance products.

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