Formation and release of fibrils and functional particles in washing process

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Review*

Most textile products under the conditions of the washing process release fibrils, which are often carriers of other chemical substances, such as micro/ nanoparticles of dyes, pigments, functional substances, surfactants and softeners that affect on environmental systems. The type and amount of released particles depends on material composition, degree of finishing, wearabilitye and washing conditions. The paper addresses the problem of the formation and release of fibrils, functional and microplastic particles (MP). Research results and examples of best practices to reduce the environmental impact of these particles are highlighted.
Keywords: *textile washing process, release of micro particles, fibrils*

1. Introduction

The properties of textiles during manufacture, use and maintenance are determined by their technological and resistance or durability. Technological durability refers to the resistance of textiles in the processes of producing and also finishing, and their resistance to light, washing, perspiration, friction and other influences related to use, wearing and care [1]. In addition to achieving the basic objectives of the finishing process, it is important to maintain the primary properties of textiles, which partly imply their durability. The effects of the process should be considered by the composition of the materials, the structural properties and condition of the materials (technological durability) as well as the combined effect of Sinner's factors during washing: mechanics, chemicals, temperature and time.

1.1. Environmental issues of the particles release

Bleaching agents and strong alkaline detergents, as well as the mechanical action of repeated washing cycles, affect changes in the surface, degree of polymerization, and tensile strength of cotton textiles. The effects of the washing process on the surface of cotton textiles, Fig.1 clearly shows a slight fibrillation after 3 and 10 washing cycles (Fig.1b and 1c), the intensity of which increases after 50 cycles (Fig.1d) and 150 cycles (Fig.1e) compared to the unwashed fabric (Fig.1a).
The potential of fibrils release depends on the type of flat textile (woven, knitted or nonwoven), texture (loose or dense), type of yarn (thread count, crimp, ring and rotor spun), type of fibers (natural, synthetic, staple or filament)

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and whether the textile has one or more components [2]. Fibrils released from textiles are often carriers of other chemical substances, ie. micro/nanoparticles, dyes, pigments, surfactants, preparations, softeners that additionally affect on environment. Today, a wide range of products is available to ensure functionality in use, and their selection must take into account possible interactions and environmental compatibility [3, 4]. Textiles, especially those made of natural fibers, represent a suitable substrate for the development of microorganisms if the environmental conditions (humidity, temperature, etc.) are appropriate [5]. The development and growth of microorganisms affect the some functional properties of textiles, safety, and/or wearing comfort [4]. The antimicrobial properties of silver have been known for a long time, and the incorporation of silver (Ag) particles into textiles with the aim of antimicrobial functionalization has been carried out for decades. The purpose of antimicrobial treatment is to prevent the development of microbes, maintain the strength, flexibility and touch of textiles, prevent unpleasant odors, improve environmental performance and durability, etc.

Although there are a large number of effective antimicrobial agents on the market that can be applied to textiles, none of them can fully meet all requirements. This concerns in particular the comfort of wearing and durability of antimicrobial protection in use, ie. during wearing (mechanical degradation) and washing (synergy of mechanical, thermal, chemical and temporal effects) [6], so it is important to monitor the migration of functional particles. Recently, however, in addition to the antimicrobial effect, the issue of Ag release from the surface of the textiles to the environment, which is related to the size of the particles, the composition of the solution, and the type of textiles, have been considered [7, 8]. It has been demonstrated that aging of the material increases the migration of silver particles from textiles that enter the wastewater through the effluent from washing machines [9]. On average, 11 μg/l are released [10, 11], which, if they enter wastewater treatment plants, can inhibit the growth of microbial cultures and reduce the efficiency of purification or, if they enter natural waters, become toxic to aquatic organisms. Fig.2 shows an example of antimicrobial functionalization of cotton socks with silver nanoparticles (AgNPs), which are released during wearing and washing and enter the environment [12].

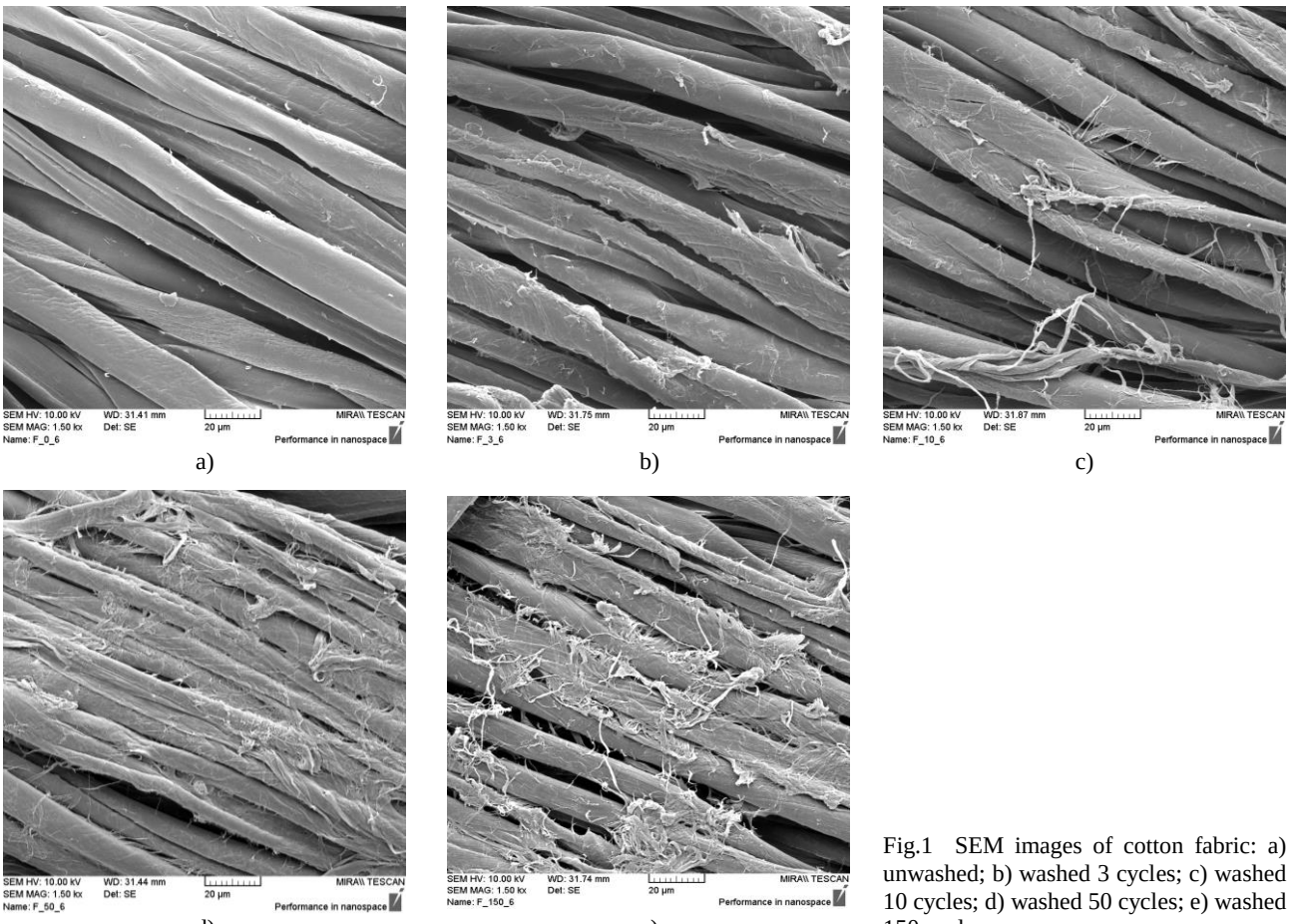


Fig.1 SEM images of cotton fabric: a) unwashed; b) washed 3 cycles; c) washed 10 cycles; d) washed 50 cycles; e) washed 150 cycles

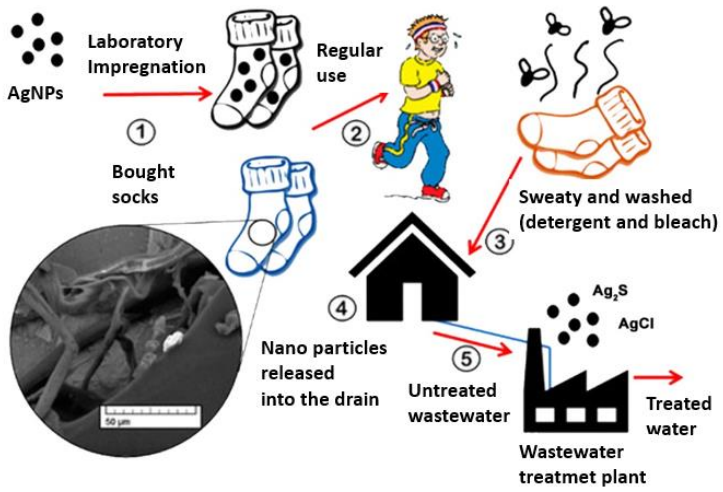


Fig. 2 Transformation of released silver nanoparticles: synthesis - textile functionalization - environment [12]

Polyester (PES) textiles are mainly made of polyethylene terephthalate, which has good technological stability due to low physical and chemical changes in the processes. PES fibers are highly crystalline, mechanically strong, hydrophobic and do not swell in water. Their heat resistance is 100°C when dry and 85°C when wet. PES textiles are washed at temperatures up to 60°C or below and retain their good dimensional stability, mechanical properties, smooth surface and color changes. The wear resistance of polyester textiles is related to the formation of abrasion and cracks that damage the surface and shorten the life cycle of the product. The formation of pilling may be associated with a slight migration of fibers that form a pill. The problem of fiber release is related to several research and testing areas, since the evaluation of fiber displacement is of particular importance for the impact of the textile industry on the environment. The problem of environmental pollution due to a large amount of microplastics (MP) and other wastes/fragments released from various sources has been known for almost two decades [13, 14].

It is estimated that 0.19 million tons of microparticles from the production and use of synthetic fibers enter the marine environment each year, with the greatest impact coming from released microparticles of fibers from textiles and plastic fragments less than 5 mm in diameter. MP is the name for plastic particles less than 5 mm in diameter associated with 2004, although the lower limit of particle size is not specified on MP [15, 16]. Despite this fact, the public has recently become more aware and shows great concern about the contamination of the aquatic environment with MP particles. Studies show that treated wastewater in the European Union contains microplastics at a concentration of 100 particles per liter. It is estimated that 2.4 mg MP per person per day is released into nature, mostly in the form of spheres, irregular fragments or fibers from various products. The sources of MP can be divided into four categories: large plastic fragments, cleaning agents, clothing as a source of fibers, and pharmaceuticals [17].

Plastics made from polymers are sometimes supplemented with copolymers and/or additives as carriers of toxic substances and generally have poor water solubility and biodegradability.

In addition, there is a high probability that even smaller particles (nanoplastics) will be created through wear and tear, which then pose an even greater risk to the environment precisely due to nature of nanoparticles.

1.2. Formation of MP particles in the washing process

Household washing of textiles has been identified as a major cause of environmental pollution with secondary microplastics in marine and aquatic ecosystems. Intensive research in recent years has focused on assessing and quantifying the impact of microparticles of fibers released during washing of synthetic textiles, Fig.3.

It was found that the amount of released PES microparticles was significantly higher under laboratory washing conditions than under real washing conditions. This relationship can be attributed to the Sinner's circle factors of the washing process, especially the filtration process and the impossibility to collect the smallest microparticles of fibers under real washing conditions. Studies have shown that filtration of wastewater can reduce the amount of MP released into the environment by 65-92% [13, 14, 19, 20].

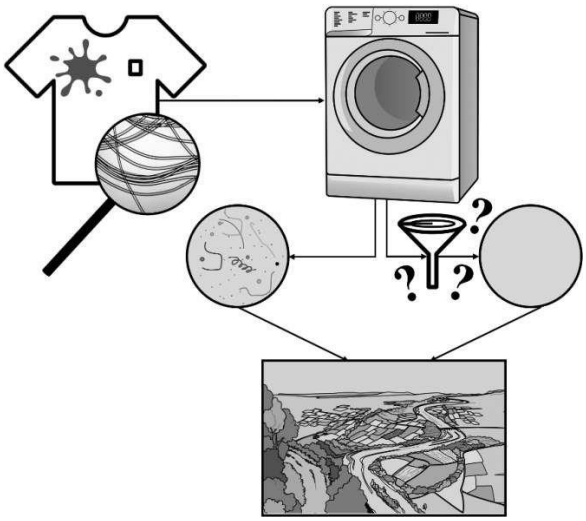


Fig.3 Graphical view of the microparticles of fibers entering to the environment from a household washing machine [18]

The problem of MP is poorly defined and potentially large, especially when the human/ ecological aspect is considered [13, 14]. Studies on the effects of released MP particles from synthetic materials showed that poly(ethylene-terephthalate) microfibers can have a lethal effect on *Daphnia magna* [21]. The toxic effect of other MP particles and physical damage to aquatic organisms were demonstrated [22]. These findings support the fact that released MP particles from various sources have become part of the food chain and thus enter the human body via marine/aquatic organisms.

1.3. Research achievements

The fact that in 2018 more than 400 scientific papers on MP generation and release were published shows the importance of this topic [23]. Despite intensive research on this issue, analytical methods are not comprehensive, which can be explained by the complexity of materials as potential donors and the physicochemical parameters of the process. In addition to a large number of scientific papers, research has also been carried out within the framework of projects. One of the most important projects is LIFE - MERMAIDS - Mitigation of microplastics impact caused by textile washing processes, LIFE13 ENV/IT/001069) [24], whose main objective was to investigate prevention and reduction of the release of MP particles in the washing process and indirectly mitigate the impact on European marine ecosystems. The specific objective of the project was to apply innovative solutions, such as detergent additives and textile treatment processes, to prevent the release of MP from synthetic clothing during the washing process. The project also aimed to develop good practice guidelines for all stakeholders: synthetic fiber manufacturers, textile industry, detergent manufacturers, households and consumers. Recommendations were made to consolidate new knowledge on MP fiber retention technologies, with the aim of achieving "good ecological status" classification by 2020 under Directive 2008/56/EC of the European Parliament and of the Council establishing a Framework for Community Action in the field of Marine Environmental Policy (Marine Strategy Framework Directive).

Research results have shown that the effects of MP particles on textiles depend on the type of material, i.e. the clothes washed, the detergent, and the settings of the washing machine. Powder detergents and high washing temperatures lead to the release of high concentrations of MP particles, while fabric softeners minimize, mainly due to reduce friction between fibers [25]. Within the mentioned project, an analytical protocol was also established based on the filtration of water from the washing of synthetic fabrics and the analysis of the filter by the method of scanning electron microscopy (SEM). The amount of MP particles released from washing polyester and polypropylene fabrics and polyester knitwear under simulated household washing conditions was quantified and statistically evaluated. The largest amount of MP was released when washing PES, and the number of microparticles of fibers released from 5 kg of laundry was estimated to be over 6 million depending on the type of detergent used. The addition of fabric softener reduced the amount of microparticles of fibers released by 35%.

Wastewater treatment plants cannot retain them, so they pose a threat to the aquatic environment. Parameters such as the amount of fibers released when washing different garments made of syn-

thetic fibers and the degree of wear at different temperatures (30 and 40°C), the presence or absence of detergent and fabric softener, water hardness, and the type of washing machine (horizontal or vertical loading) were quantified by gravimetric analysis. The results of the study of the washing process of clothes without detergent in a washing machine with horizontal and vertical loading showed that the mass of microparticles of fibers produced in a machine with vertical loading is about seven times greater than in a machine with horizontal loading. Clothing that was mechanically treated (worn out) by continuous washing for 24 hours according to the same protocol as new clothing increased the amount of microparticles of fibers released, although the results of statistical analysis ANOVA showed no significance between aging and filter size and the type of washing machine loading [26].

Members of the American Association AATCC (*American Asociation of Textile Chemists and Colorists*) *Committee* RA 100, *Global Sustainability*, are working on setting of a laundering process that can control the release of microparticles of fibers during household laundering such that the process simulates household laundering [27].

The original idea of the *Seabin* project (Fig.4) was to build a sustainable floating trash container that could collect plastic and trash in the water 24 hours a day. Over time, the need to clean the water of MP particles and microfibers is disseminated. Through research and innovation, suitable solutions to capture microplastic particles, microparticles of fibers and pads that adsorb petroleum and detergent-based surface oils, all of which are widely used in most marinas around the world have been developed. Through *Seabin* technology, current ecological problems are being solved, with the goal of improving the state of Planet [28].

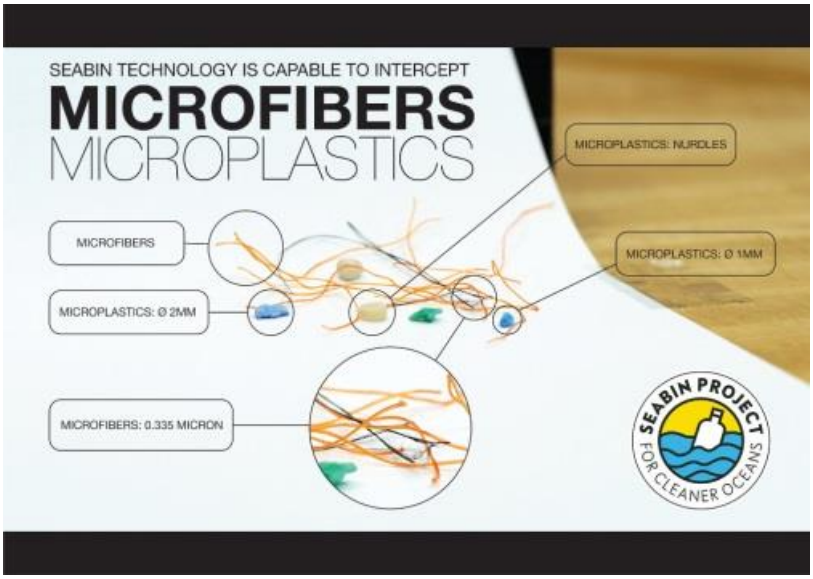
Since 2014, the renowned German Fraunhofer Institute has been conducting intensive research on MP particles in projects and project studies [23]:

- project study *Plastics in the Evironment: Micro- and Macro- plastics*, published in 2018,
- project study *Microplastics in Cosmetics and Detergents*, published in 2018,
- project *TyreWearMapping* (2017-2020),
- project *PlastikBudget* (2018-2021),
- project *FibrEX* (2018-2020),
- project *iMulch* (2019-2022).

1.4. Examples of good practice

Preventing the release of MP particles from clothing into the environment requires changes and actions at many points in the supply chain. An example of good practice in the development of materials that have a low MP release potential is the collaboration between the Italian textile manufacturer *Eurojersey* and the research institution *National Research Center* from Italy. An encouraging result of this collaboration is a compact textile structure obtained by continuous spinning, which has a limited release of MP compared to other fabrics of a similar category [29].

Xeros has licensed XFiltra™, a filter for household washing machines designed to reduce microparticles of fibers contamination when washing clothes (Fig.5) [30].



a) b)

Fig.4 Seabin project: a) logo; b) Seabin technology [28]

Fig.5 X Filtra™ - washing machine filter [30]

The filter is designed to capture 99% of the various types of MP particles released from clothing during the household washing cycle. This innovative, patented solution is being offered to washing machine manufacturers, retailers and brands to help reduce pollution from microplastics, the largest primary source in the ocean. In the literature, the innovative filter is cited as a cost-effective solution to the current environmental problem of plastic pollution [30].

2. Conclusion

A comprehensive analysis of the literature published to date on the issues of released microparticles of fibers in washing machines has shown that great efforts are being made to find a solution to the global problem. Studies and project research results have provided insight into the behavior of different types of textiles during their life cycle (lifespan), with their partial release into the environment in different ways, where they accumulate due to their poor biodegradability, leading to serious environmental problems after some time [31]. Nevertheless, it is often considered that it is necessary to intensify the studies on the release of microparticles of fibers into the environment. By adopting innovative and environmentally friendly processing methods for synthetic materials and their proper maintenance, the release of MP particles into the environment can be significantly reduced. However, no system has yet been confirmed to have a preventive effect on the release of microparticles of fibers into the aquatic environment and to have no harmful effects on the washing process and/or the washing result [32].

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