Analyzing the Influence of Physical and Chemical Finishing Treatments on Microplastic Emission from Knitted Fabrics during Laundering

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I. Introduction

Microplastic fibers are a significant component of plastic pollution in aquatic environments, posing substantial risks to marine organisms due to their small size[1][2][3]. The textile industry extensively uses synthetic plastic fibers and is a key contributor to microplastic pollution[4]. Laundering of synthetic textiles has been recognized as a critical pathway for microfiber release, with domestic washing processes contributing substantially to microplastic pollution[5]. Understanding the mechanisms of fiber release during laundry, as well as the influence of textile parameters, is therefore essential for developing effective mitigation strategies and reducing the environmental burden of textile derived microplastics[6]. This study specifically focuses on the impact of different textile finishing treatments during laundering and how these treatments influence microplastic fiber release.

II. Literature Review

A. Microplastics

Plastic particles between 5 mm and 1 µm are categorized as microplastics. Fiber-shaped microplastics are specifically defined as particles with a length between 300 nm and 15 mm and a diameter-to-length ratio greater than 3[7]. Textiles contribute to microplastic pollution when synthetic fibers break down into tiny, fiber-like particles, often referred to as fiber fragments or fibrous microplastics[8].

B. Microplastic release mechanism from the fabric.

Fiber shedding is the detachment of loose or damaged fibers from textiles, primarily driven by mechanical stress, abrasion, and pilling[9]. Abrasion occurs during production, regular use, and laundering, where physical forces such as water agitation, fabric movement, and impact cause fiber to break and detach, contributing to microplastic release[4][10]. Repeated moderate stress, rather than single intense forces, is the main cause of fiber damage. Pilling, resulting from fiber entanglement and fuzz formation, further accelerates fiber loss during washing. Overall, laundering imposes greater mechanical stress on textiles than regular wear, significantly influencing fiber shedding and the subsequent release of microplastics.

C. Factors affecting microplastic release from textiles during the laundering process

Textile characteristics and washing parameters significantly influence microfiber release. Key textile factors include fiber composition, yarn type and twist, fabric structure, construction tightness, finishing treatments, and fabric aging. Fiber composition plays a significant role, with polyester being the most widely used fiber and shedding more microplastics than other fibers[11]. Spun yarns release more than filament yarns due to shorter fibers, while within filament yarns, non-twist types shed more than high-twist yarns[4]. knitted fabrics release more than woven fabrics because of their loose loops, and among woven types, twill sheds more than plain weave[10]. Finishing treatments significantly influences shedding, as mechanical processes like brushing and raising damage fibers and increase release processed fabrics can shed up to five times more than untreated ones. Chemical coatings, such as anti-pill finishes, reduce shedding initially but lose effectiveness after repeated washing[2]. Aging and wear further increase emissions, with aged polyester garments shedding about 25% more than new ones due to fraying and degradation[9]. Overall, fiber type, yarn and fabric structure, finishing, and aging are key determinants of microplastic release during washing.

Washing parameters such as water temperature, detergent type, mechanical agitation, water volume, washing cycle duration, and machine settings directly affect microfiber shedding. Higher washing temperatures (around 40 °C) weaken fabric binding forces, leading to greater microfiber release, though the amount decreases as the wash progresses due to reduced physical force[4]. Detergents also contribute, both mechanically and chemically, by cleaning surface contaminants but simultaneously damaging fibers, powder

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detergents causing the most shedding because of insoluble particles and zeolite that increase friction, while liquid detergents cause less. Agitation, driven by drum size, configuration, rotational speed, and wash liquor ratio, intensifies microfiber release as mechanical action increases [3]. Similarly, a high water-to-fabric ratio keeps loosened fibers suspended and prevents redeposition, allowing more fibers to escape into wastewater[13]. Studies further show that most microfibers are shed during the first wash cycle, with subsequent washes releasing significantly fewer[4][2]. Finally, washing machine settings such as rotational speed, liquor ratio, and cycle duration play a major role, with higher speeds and longer wash times leading to greater microfiber emissions[4].

III. MATERIALS AND METHODS.

This study investigated the impact of physical and chemical finishing treatments on microplastic emissions from knitted fabrics during laundering. Fabric samples were evaluated before and after finishing, subjected to standardized simulated domestic washing, and the effluent was filtered to collect released microplastics. Quantitative analysis of the captured fibers was conducted to determine the influence of different finishing treatments, with all experimental procedures aligned to AATCC TM212-2021 standards to ensure accuracy and reproducibility.

A. Fabric collection for testing

The study focused on knitted fabrics, which are more prone to fiber release due to their loose structure. Three different fabrics were selected: the first underwent brushing, shearing, tumble drying, and stentering; the second was treated only with sueding; and the third was treated with only chemical hydrophilic softener treatment. Primarily 100% synthetic fabrics, especially polyester, were chosen due to their widespread use. Samples were collected before and after finishing to directly compare microplastic release, isolating the effects of finishing treatments while keeping other textile parameters constant.

B. Preparation for fabric Swatches

For each fabric, three swatches (34 × 20 cm) were cut from random locations to ensure statistical reliability and minimize sampling bias. To prevent microfiber release from cut edges, swatches were folded and sewn using a single-needle lockstitch machine at 2.5 stitches/cm. Although filament threads are preferred to minimize shedding, spun threads of a different color were used to distinguish fibers originating from sewing, ensuring accurate analysis of microplastic emissions from the fabric.

C. Washing and water sample collection

Domestic laundering was simulated using a Gyrowash machine with eight 1200 mL canisters, operating at 40 RPM and 40°C for 45 minutes with 360 mL of distilled, filtered water. Fabrics were pre-washed to remove loose fibers, and 1.25 mL of liquid detergent was added to minimize abrasion and prevent filter clogging. Mechanical agitation was simulated using 50 steel balls per canister. After washing, effluent was collected in sealed glass bottles to ensure accurate and reliable microplastic analysis.

D. Filtering

Microplastics were separated using vacuum filtration with Whatman GF/D filter paper (1.2 µm pore size, 47 mm diameter). Due to high fiber concentration in 360 mL of effluent, 150 mL was analyzed in three 50 mL portions to prevent entanglement and allow statistical evaluation. Filter papers with collected microplastics were carefully transferred to labeled Petri dishes and stored under controlled conditions before stereomicroscopic quantification and characterization.

E. Quantification of microplastic

Gravimetric analysis was employed to measure the total mass of collected microplastics, with filter papers pre-dried and weighed before and after filtration to estimate fiber shedding. Count analysis determined the number of fibers per sample using a stereomicroscope and Image Focus Alpha software, Length and shape analysis assessed fiber size distribution and fragmentation using the software's measurement tool, providing a representative evaluation of microplastic characteristics across the samples.

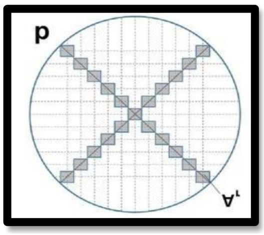


Figure 1 : Counting Method

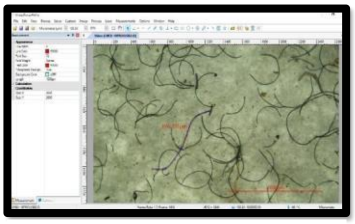


Figure 2 : Image focus Alpha Software

IV. RESULTS AND DISCUSSION

The fabric treated with hydrophilic silicone softener showed a reduction in microplastic release. The untreated fabric released an average of 17.33 mg/L, while after treatment, the release decreased to 12.67 mg/L, indicating a reduction of 4.66 mg/L. From the count analysis, the fabric released 927 microfibers before and 818 microfibers after chemical treatment. Length analysis results show that microfiber lengths ranged from 10 µm to over 1 mm, with the majority between 100–700 µm, and the distribution remained similar before and after hydrophilic softener treatment. The results indicate that fabrics treated with a hydrophilic silicone softener release significantly fewer microplastics during washing compared to untreated fabrics. The decrease in microplastic release is primarily due to the softener forming a thin protective layer on the fiber surface, which reduces friction between fibers and mechanical stress during laundering, thereby minimizing fiber breakage.

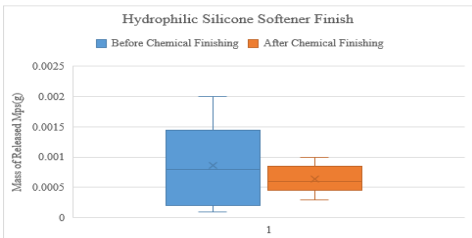


Figure 3 : Box Plot for Hydrophilic Silicone Softener Finish

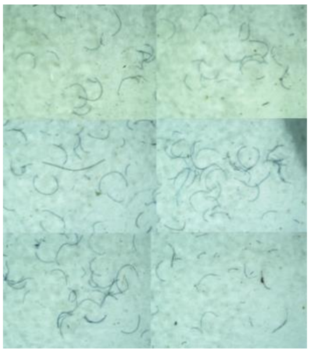


Figure 4 : Microscopic image for before hydrophilic silicone softener finish

Figure 5 : Microscopic image for After hydrophilic silicone softener finish

The fabric treated with sueding/peaching showed an increase in microplastic release. The untreated fabric released an average of 12.67 mg/L, while after sueding, the release increased to 15.33 mg/L, indicating an increase of 2.66 mg/L. From the count analysis, the fabric released 848 microfibers before and 863 microfibers after the sueding/peaching treatment. Length distribution analysis shows that while the overall range of microplastic fibers remains similar before and after sueding/peaching, the number of fibers in the 50–250 µm range increased, indicating a slight rise in finer microfiber release. The results indicate that sueded or peached fabrics release more microplastics during domestic washing, particularly finer fibers. This increase is attributed to the sueding process, where rollers with abrasive surfaces raise fine surface fibers to create a soft texture. Mechanical friction and abrasion also weaken yarns and fibers, making them more prone to shedding.

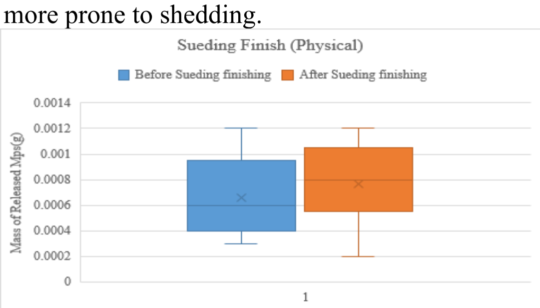
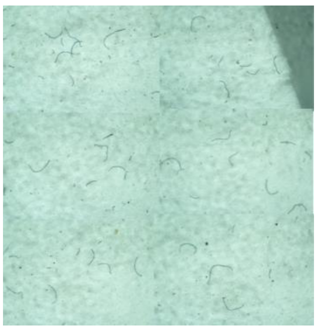


Figure 6 : Box Plot for Sueding Finish (Physical)



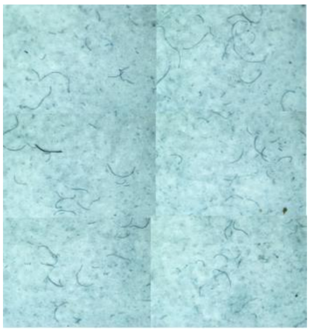


Figure 7 : Microscopic image for Before Sueding Finish Fabric

Figure 8 : Microscopic image for After Sueding Finish Fabric

The fabric treated in the brushing line released varying amounts of microplastics at different stages of the brushing line. Before brushing, the release was 14 mg/L, which increased to 24.67 mg/L after brushing. After combing and shearing, it reached 27.33 mg/L, then decreased to 16.67 mg/L after anti-pilling/tumble drying and finally measured 19.33 mg/L after stentering. These results show that each finishing stage influences microplastic shedding during laundering. From the count analysis, the fabric released 621 microfibers before brushing, which increased to 953 fibers after brushing. After combing and shearing, 1,292 fibers were released, followed by 1,014 fibers after tumble drying, and 1,336 fibers after stentering. The length distribution analysis shows that before brushing, most fibers ranged from 100 µm to 1 mm. After brushing, the distribution shifted left, with most fibers between 50–550 µm, indicating shorter fibers are released. Shearing increased the frequency of fibers in the 100–250 µm range, nearly doubling compared to brushed fabric. After tumble drying, the frequency decreased, while stentering increased microfiber release again. The results show that different finishing processes on the brushing line affect microplastic release during laundering. Brushing significantly increases microfiber shedding due to the raised, fuzzy surface created by metal-pin rollers, which weakens the yarn structure and produces short fibers that break off easily. Combing and shearing further increase release by aligning and trimming these raised fibers, generating shorter microplastics. In contrast, tumble drying (anti-pilling) reduces microplastic release by removing loose fibers and stabilizing the fabric surface through controlled heat and friction. Stentering, however, increases microfiber shedding again, as the combination of high temperatures and mechanical tension can weaken polyester fibers, making them more prone to breakage during washing. Overall, mechanical and thermal treatments alter fiber exposure and strength, influencing the quantity and size of microplastics released.

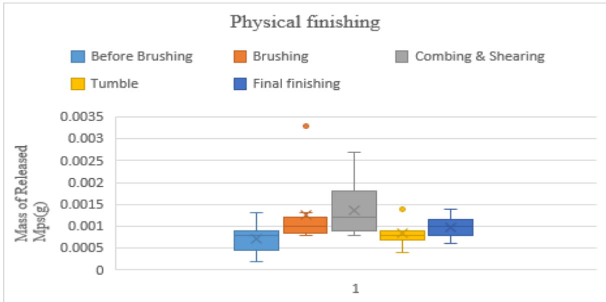


Figure 9 : Box Plot for of Brushing, Combing & Shearing, Tumble and Final finishing (Physical)

V. CONCLUSION

This study evaluated the impact of various chemical and physical finishing processes on microplastic release from synthetic fabrics during domestic laundering. Six finishing brushing, shearing, tumble drying (anti-pilling), stentering, sueding, and hydrophilic softener application were examined. All fabrics release microplastics, confirming laundering as a significant pollution source. Brushing and shearing increased microplastic release, particularly of finer fibers, due to surface damage and fiber trimming, while tumble drying reduced shedding by removing loose fibers and stabilizing the surface. Stentering increased release due to high heat and tension weakening fibers, whereas hydrophilic softener effectively decreased microplastic emission without altering fiber length, by forming a protective surface coating. These findings suggest that combining mechanical and chemical finishing strategies such as anti-pilling tumble drying and hydrophilic softener application, can mitigate microfiber shedding. Optimizing laundering parameters (temperature, agitation, detergent, load size) and promoting consumer awareness are also critical. Collectively, these approaches can reduce microplastic pollution while maintaining fabric performance and comfort.

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