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Commentary

Functional polymer brushes for anti-microplastic pollution

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Microplastic fibers (MPFs) featuring mean sizes of 11–5,000 μm and lengths of less than 500 μm have been regarded as ubiquitous and hazardous contaminants in the ecosystem [1,2]. Nowadays, nearly 35% of MPFs come from textile washing [3], threatening freshwater, marine fauna, human life, and even ecological balance on multiple scales. The controllable release of MPFs during garment washing has become increasingly urgent [4].

Using different resins (e.g., acrylic, polyurethane, and silicon-based resins), the textile finishing is used to modify various fibers, such as polyester and polyamide, before evaluating the pilling resistance. Silicon-based resins finished fabrics possess a higher reduction in MPF shedding. In view of the potential sustainability of synthetic finishes, subsequent studies adopted naturally inspired agents, like chitosan and pectin [5,6]. Falco et al. [6] found that the pectin-treated polyamide fabric can generate less than 90% MPFs. However, these studies mainly focus on effectiveness, while the underlying mechanisms are rarely illustrated. In addition, there is a lack of emphasis on the effect of these surface finishes on the inherent handle and textile properties, which are desired for the fabric.

Lahiri et al. [7] recently developed a robust nylon fabric grafted with polydimethylsiloxane (PDMS) brushes by a two-layer coating approach. The coated fabric could ideally sustain their multifunctional properties, such as water-repellency, comfort, air permeability, and low friction in wet and dry states. Moreover, it significantly reduced 93% of MPF formation even treated with cycled laundering.

Coating technology is an effective strategy to strengthen the mechanical robustness of the prepared surface [8]. Thereinto, interlayer adhesives are typically adopted to anchor functional coatings on desired substrates via physical [9] and chemical [10] bonding. Herein, Lahiri et al. [7] first prepared the primer of 3-mercaptopropyltrimethoxysilane (MPTMS) on the nylon and then generated sulfonic-acid-functionalized MPTMS (Fig. 1a). Next, PDMS brushes were firmly coated on primer-nylon, arising from the ionic coupling of MPTMS and PDMS. The chosen primer, MPTMS, built a solid bridge between nylon and PDMS brushes, ensuring the multifunction of the coated fabric nylon. Based on the data provided in Lahiri's work [7], the cost accounting of the raw materials or chemicals is about $9.68 for the fabric within the surface size of 1 m^2.

To demonstrate the performances of anti-microplastic pollution, five samples (i.e., untreated, softener, primer-treated, PDMS-brush-treated, and primer–PDMS-brush-treated fabrics) were prepared to test the microfibers in laundering sewage (Fig. 1b). The untreated one released a high number of MPFs (3,975 ± 327 fibers per gram of fabric sample). For one gram of primer–PDMS fabric, only 289 ± 75 of MPFs were observed with a ~93% reduction compared with the untreated one. Even when the temperature was increased from 40 °C to 60 °C as well as the duration time was adjusted from 1 h to 24 h, there was almost no obvious variation in the number of released MPFs for the primer–PDMS fabric. In contrast, the untreated fabric displayed a sharp increase in the production of MPFs under the above conditions. Therefore, it can be concluded that the two-layer structure (e.g., primer–PDMS layer) plays a decisive role in the robustness of the fabric, minimizing microplastic pollution.

As known (super)hydrophobic surfaces are commonly fabricated by low surface energy modifications and micro-/nano-structures constructions [11]. PDMS is an eco-friendly fluorine-free polymer with low surface energy and flexible structure [12]. After nine washing repeats, the hydrophobicity of the pristine fabric would shift into hydrophilicity with the advancing/receding water contact angles (WCAs) decreasing from 110°/97° to 74°/48° (Fig. 1c). The loss of water-repelled property on untreated fabric can be inferred as structural damage or reduced fluoride contents. Benefiting from the existence of PDMS brushes, the primer-PDMS fabric was highly hydrophobic with advancing/receding WCAs of 141°/129°. The coated one almost remained water repellency with a slight decrease in WCAs (128°/97°) even after multiple washing cycles. Generally, a (super)hydrophobic surface shows (super)aerophilicity [13]. Thus, air would diffuse more easily across this surface, providing better comfort and air permeability of the coated nylon fabric.

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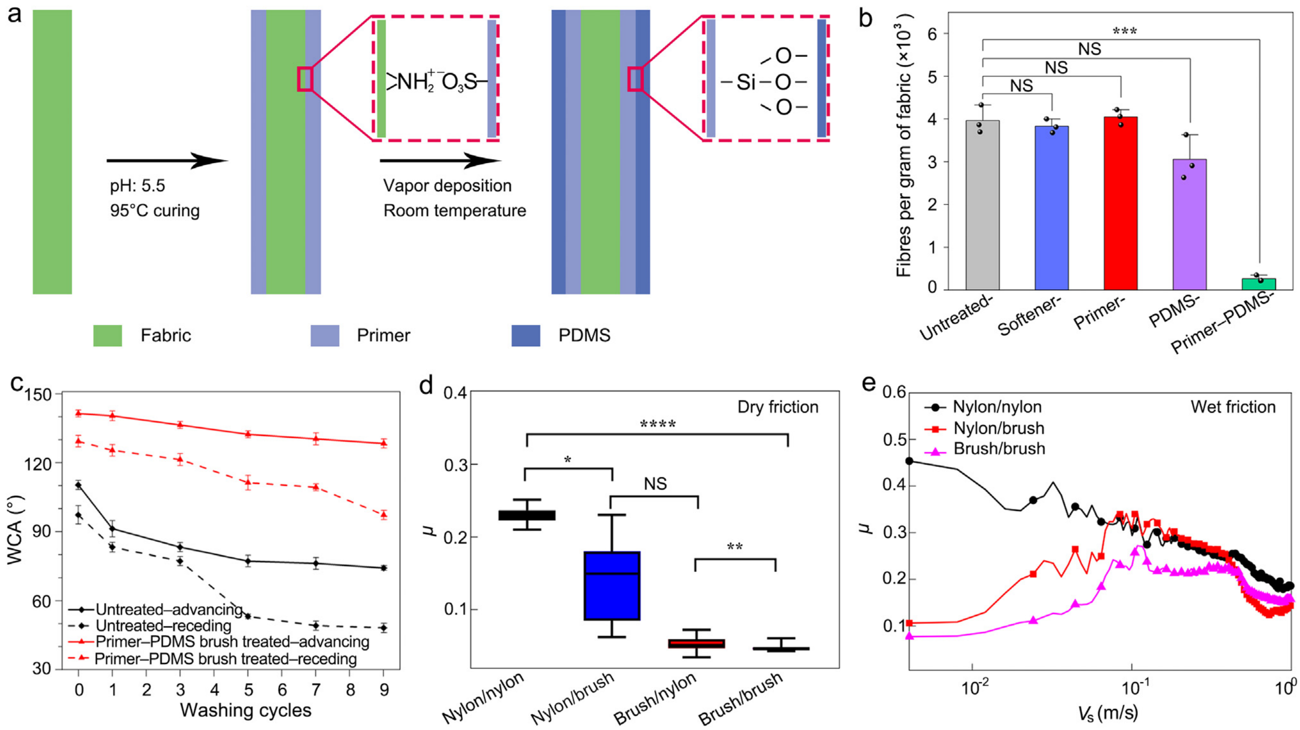

Fig. 1. (a) Two-layer coatings were used to prepare the multifunctional nylon fabric, and the interlayer (i.e., primer) was used as a chemical bond between the fabric and PDMS brushes. (b) MPFs releases for different fabric samples. (c) Water contact angle (WCA) variations of the untreated and treated fabrics. The dry (d) and wet (e) friction factors of different fabric samples. Panels b–e adapted with permission from ref. [7]. Copyright (2023) Springer Nature. PDMS, polydimethylsiloxane; MPF, microplastic fiber; NS, not significant (P value > 0.05); *Student's t-test P value < 0.05; **Students's t-test P value < 0.01; ****Student's t-test P value < 0.001; μ, friction factor; V_s, sliding velocity.

The dry and wet frictions on the primer–PDMS fabrics were tested to exhibit the performances of microplastic minimization. Four ball/disc models were applied to illustrate the dry frictions (Fig. 1d), i.e., nylon/nylon, nylon/brush, brush/nylon, and brush/brush. The bare fabric (nylon/nylon) possessed the highest friction factor ($\mu = 0.230$). As for the nylon/brush and brush/nylon ones, both friction factors decreased and have identical values (i.e., $\mu = 0.150$). A minimum friction factor of 0.052 was found on the primer–PDMS fabric. PDMS with a flexible structure and low surface energy was well propitious to achieve a slippery surface and greatly reduced solid friction [14], thus enhancing the reduction of MPFs shedding during laundering. In regard to wet friction (Fig. 1e), the commercial detergent solution was utilized as the lubricating agent to study the Stribeck curves of different fabrics. When the sliding velocity (V_s) was lower than 10^{-1} m/s, the wet friction factor of the untreated fabrics decreased but was still larger than that of the PDMS-treated and primer–PDMS-treated fabrics. Once V_s was larger than 10^{-1} m/s, all wet friction factors on these three samples decreased with similar tendencies. The primer–PDMS-treated nylon fabric sustained a stable wet friction factor in relatively low value, thus prohibiting the formation MPFs during cycled laundering.

Currently, various methods have been proposed to prevent microplastic pollution from textile washing. Mitigation strategies consist of two main aspects, i.e., the regulations and laws to manage microplastic pollution as well as the public (e.g., industry and consumer) awareness to reduce microplastic emissions. Many studies have explored the effect of washing parameters and conditions (e.g., water-volume ratio [15], temperature, detergents, wash duration, and spin speed [16,17]) on MPF shedding. Moreover, some researchers have proposed using enzymes to break down microfibers during the washing process. Different from the physical, chemical, and biological treatments of microplastic from wastewater in most reported works these days [18], Lahiri et al. [7] developed a facile, easy-to-operate, sustainable coating strategy to prevent MPFs from textile washing at the source. Future research requires multidisciplinary integration, including material science, engineering, and environmental science, to mutually reduce the microplastic pollution from textile washing. Finding solutions that are sustainable, cost-effective, durable, effective, and can be adopted by consumers and manufacturers is a significant challenge and an area for future research efforts.

Author contributions

Conceptualization: L.Y.W. and H.Z. Data curation, funding acquisition, investigation, project administration, software, validation and roles/writing–original draft: P.F.S. and H.Z. Formal analysis: P.F.S., C.R. and L.Y.M. Methodology: P.F.S., L.Y.M. and L.Y.W. Resources and visualization: P.F.S. and C.R. Supervision, writing–review and editing: L.Y.W. and H.Z.

Declaration of competing interest

The authors declare no conflicts of interest.

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