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EMERGING CONCERNS OF NON-WOVEN ABRASIVE MICROFIBERS IN ENVIRONMENTAL SYSTEMS

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ABSTRACT

Non-woven abrasive materials, widely used in domestic and industrial cleaning applications, represent an underexplored source of microplastic pollution. These materials are typically composed of synthetic polymeric fibers, such as polyamide or polyester, integrated with inorganic abrasive particles and bound through thermoset or thermoplastic resins. During routine use, mechanical wear and friction induce the release of microfibers and particulate debris into wastewater streams. This short study highlights the chemical composition, degradation pathways, and environmental implications of such emissions. Particular emphasis is placed on the persistence of polymeric fragments, their interaction with co-existing pollutants, and their potential to act as vectors for toxic substances in aquatic and terrestrial systems.

Keywords: Non-woven abrasives, microfibers, microplastics, polymer degradation, environmental pollution, bio-composites.

INTRODUCTION

Global concern regarding microplastic pollution has intensified due to its pervasive distribution across aquatic and terrestrial ecosystems, where persistent polymer fragments interact with biotic and abiotic components (1,2). While major contributors such as packaging debris and textile-derived fibers have been extensively characterized, comparatively less attention has been directed toward non-woven abrasive materials used in household and industrial cleaning applications (3). These materials are typically engineered composites consisting of synthetic polymeric microfibers—commonly polyamide, polyester, or polypropylene—interlinked with abrasive mineral particulates and bonding resins. During routine usage, repeated mechanical abrasion, shear stress, and chemical exposure promote structural degradation, leading to progressive fragmentation and the release of microfibrous debris into wastewater systems (4). Recent studies emphasized that these abrasive-derived microfibers constitute an emerging (5,6,9,10) yet previously underestimated source of environmental microplastics (7). Unlike conventional fibers, their irregular morphology, composite chemistry, and enhanced surface reactivity may facilitate adsorption of heavy metals, organic pollutants, and microbial communities, thereby influencing contaminant transport and trophic transfer processes. Furthermore, their resistance to biodegradation and potential to evade conventional wastewater treatment mechanisms amplify their environmental persistence (8). The widespread and increasing use of such abrasive products, combined with limited regulatory oversight, underscores the urgency for systematic investigation. In the current study, we explore a comprehensive understanding of their physicochemical characteristics, release dynamics, and ecological interactions. It is essential to accurately assess their contribution to global microplastic pollution and to inform sustainable material design and mitigation strategies.

CHEMICAL COMPOSITION AND STRUCTURAL COMPLEXITY

Non-woven abrasive pads are composite systems consisting primarily of synthetic polymers such as nylon (polyamide) and polyethylene terephthalate [19,20]. These polymers provide flexibility and mechanical integrity, while abrasive particles such as aluminum oxide and silicon carbide impart cleaning efficiency [17]. The components are bonded using polymeric resins, resulting in a three-dimensional porous architecture [18]. This structural heterogeneity complicates degradation pathways and environmental interactions [22,24]. Types of abrasives are elicited concisely in Figure-1.

Figure-1. Types of abrasives.

3. Mechanisms of Microfiber Generation

Mechanical abrasion is the primary mechanism governing microfiber release during the use of non-woven abrasive materials [15]. Repeated frictional forces induce fiber fatigue, resulting in fragmentation and detachment of embedded abrasive particles [22]. Concurrently, chemical degradation processes, including hydrolysis, oxidative reactions, and UV-induced polymer chain scission, further weaken the structural integrity of fibers [20,26]. These combined effects enhance the release of microfibers, which are subsequently transported through wastewater systems, acting as major pathways for their entry into aquatic environments [27]. Textile mechanical finishing comparison depicted in Figure- 2.

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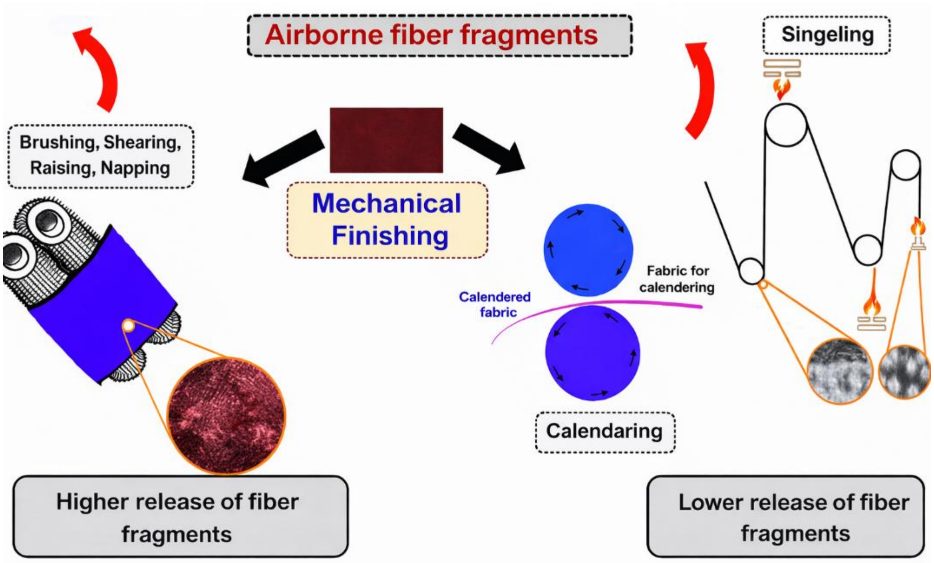

Figure 2. Textile mechanical finishing comparison.

ENVIRONMENTAL DISTRIBUTION AND TRANSPORT

Microfibers originating from abrasive materials have been widely detected in freshwater, marine environments, and sediments [28,29]. Their elongated morphology enhances dispersibility, enabling long-range transport through hydrodynamic flow and atmospheric pathways [30]. Additionally, accumulation in agricultural soils has been reported due to land application of wastewater-derived sludge [31]. The persistence of these microfibers is primarily governed by the inherent resistance of synthetic polymer matrices to biodegradation and environmental weathering processes [23,26], thereby contributing to their prolonged residence and ecological impact. Figure- 3 consists of microplastic pathways from societal plastic use, synthetic textiles, and primary microplastic manufacture to marine environment.

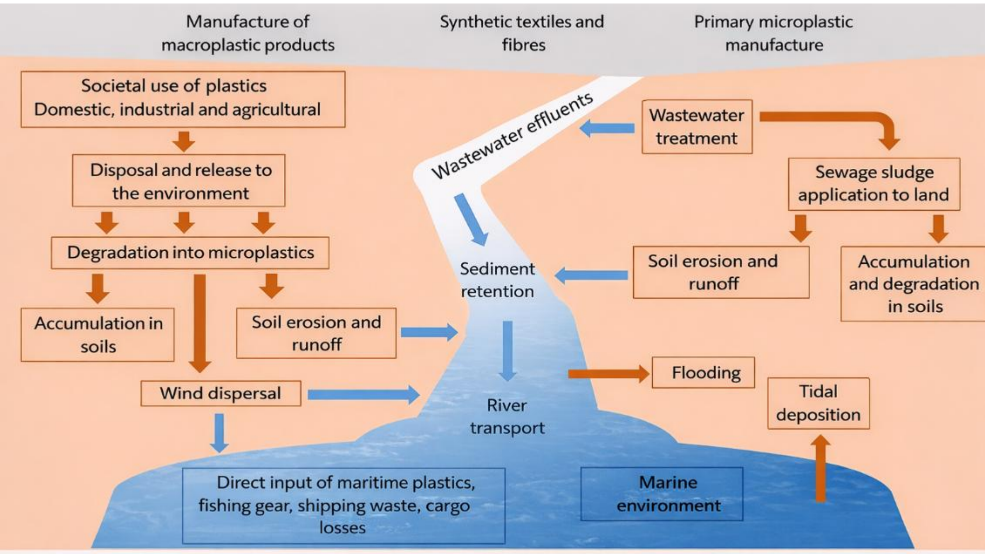

Figure-3. Microplastic pathways from societal plastic use, synthetic textiles, and primary microplastic manufacture to **marine environment.**

INTERACTION WITH POLLUTANTS

One of the critical environmental concerns associated with microfiber pollution is their strong affinity for contaminants, including heavy metals, synthetic dyes, and hydrophobic organic compounds [7,26]. The large specific surface area and the presence of functional groups on polymer chains significantly enhance adsorption capacity [22]. As a result, these microfibers function as effective carriers, facilitating the transport, accumulation, and increased bioavailability of toxic substances within aquatic and terrestrial ecosystems, thereby amplifying ecological and toxicological risks [28].

ECOTOXICOLOGICAL EFFECTS

The ingestion of microfibers by aquatic organisms has been extensively documented [2,6], leading to adverse physiological effects. These particles can induce physical blockage, impair feeding behavior, and reduce nutrient assimilation [28]. Additionally, the release of additives and adsorbed contaminants may trigger oxidative stress, inflammatory responses, and cellular toxicity [23]. Their irregular morphology and abrasive characteristics further intensify biological damage compared to smoother microplastic particles [22]. The illustration depicts the ecotoxicological impacts of microplastics and associated pollutants on aquatic and terrestrial organisms, showing ingestion, accumulation, and physiological damage across species (Image-1).

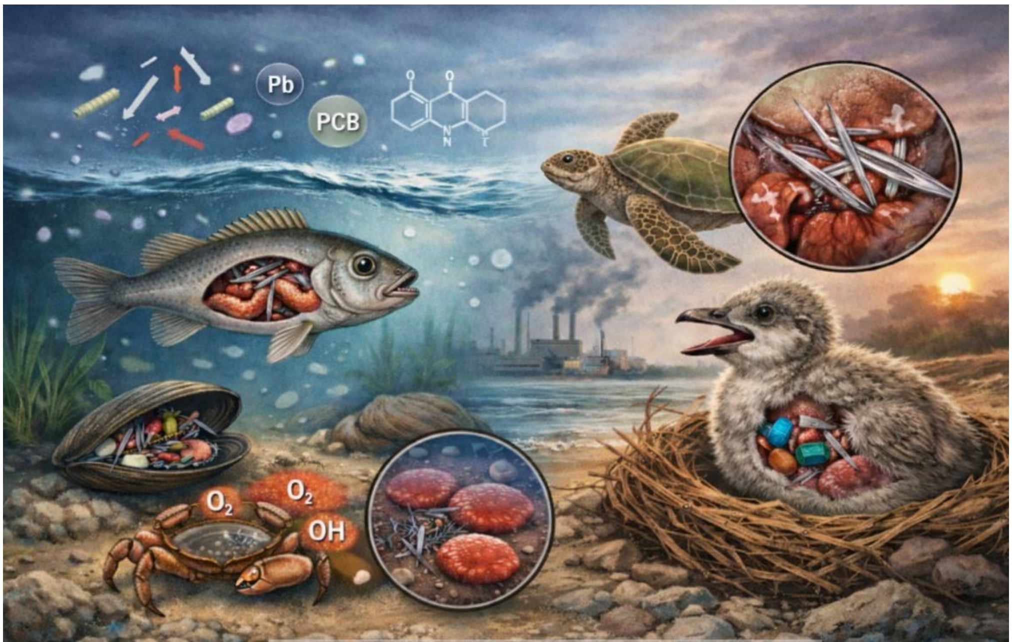

Image-1. Illustration of ecotoxicological Effects.

EMERGING CONCERNS AND RESEARCH GAPS

Despite increasing awareness, significant research gaps persist. Standardized analytical methods for quantifying microfiber release from non-woven abrasives remain limited [21]. Long-term degradation behavior and environmental fate modeling are still inadequately understood [20,26]. Furthermore, the role of biofilm formation and microbial colonization in altering microfiber transport, persistence, and pollutant interactions requires systematic investigation [30]. Addressing these gaps is essential for accurate risk assessment and development of effective mitigation strategies.

SUSTAINABLE PERSPECTIVES

The development of eco-friendly alternatives, including bio-based fibers and biodegradable binders, is gaining increasing attention as a sustainable solution to microfiber pollution [28]. These materials aim to replace petroleum-derived polymers with renewable and degradable constituents. However, achieving an optimal balance between mechanical performance, durability, and environmental safety remains a significant challenge. The integration of green

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chemistry principles, such as the use of non-toxic reagents and energy-efficient processing, alongside circular economy strategies, is crucial for minimizing environmental impact and promoting material sustainability [5,20]. Continued research is required to enhance functionality while ensuring ecological compatibility.

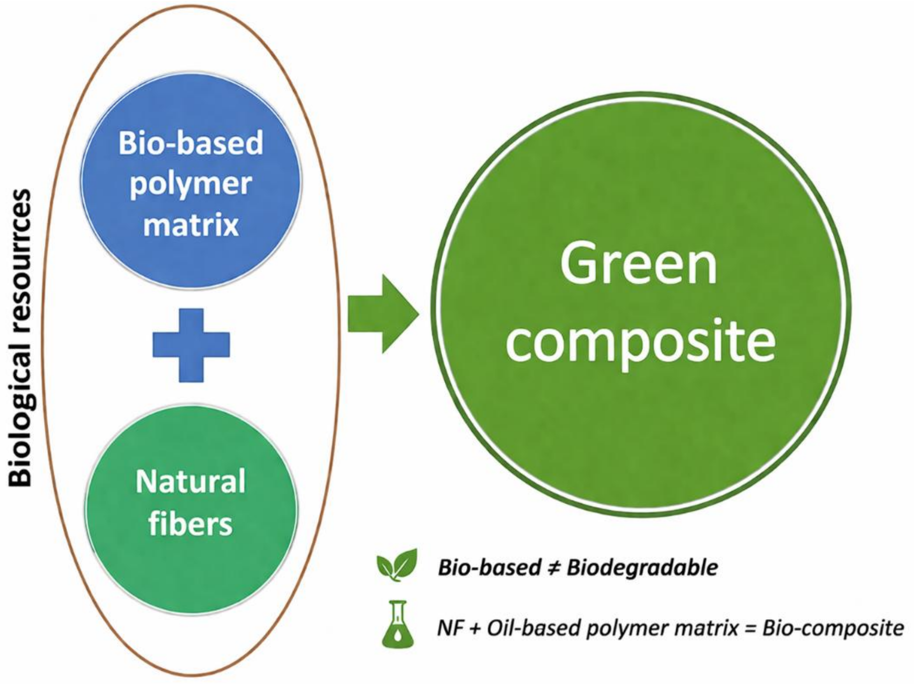

Figure-4. Green composite diagram with bio-based components.

Conclusion

Non-woven abrasive microfibers constitute a largely overlooked yet consequential source of microplastic pollution, raising critical concerns regarding their long-term environmental persistence and reactivity. Their heterogeneous composition not only complicates degradation pathways but also enhances their capacity to sorb and transport toxic contaminants, thereby amplifying ecological risks. The absence of standardized monitoring frameworks and limited regulatory focus further exacerbate the issue. Without targeted intervention, their cumulative impact may be substantially underestimated. Therefore, integrating stringent regulations, advancing biodegradable material design, 3D designing and improving wastewater treatment technologies are imperative to effectively mitigate their environmental footprint.

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