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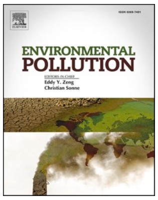

Surfactants can compete with microplastics for surfaces using adhesives as substrates for microplastic sequestration☆

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ABSTRACT

Experimental efforts supplemented by modeling gauged whether common additives found in soaps and laundry detergents interfered with polyacrylate adhesive-based capture of microplastics. On the experimental front, poly (2-ethylhexyl acrylate) (PEHA) samples were evaluated using gravimetric analysis, probe tack, and functional assessments of adhesive-coated glass slides immersed into DI water solutions containing both microparticles and additives (solvents, softeners, and non-ionic surfactants). Nylon-6 spheres and polyethylene terephthalate microplastics were chosen for adsorption using a count-based method by ImageJ imaging analysis. Molecular dynamics computations simulated 2-ethyl-hexylacrylate (2-EHA) adhesive and microplastic interactions in the presence of water, citrate, glycerol and tergitol detergent additives. The experimental work showed that fewer microplastics were collected when tergitol was added and was in line with lower experimental Work of Adhesion (WoAaq) results for nylon and PETE (94.5% and 54.5% reductions respectively). Computational results also confirmed lower adhesion in the presence of tergitol. The experiments also showed that the adhesive swelled while equilibrating in additive solutions. Models suggested that tergitol most negatively impacted particle binding through a competitive "blocking" of the adhesive substrate while the other additives were less conclusive about potential interferences based on competitive binding.

1. Introduction

Laundering of synthetic fabrics is a common entry point for textile-derived microplastics (MPs) into wastewater systems (Azanaw et al., 2022; Palacios-Marín et al., 2022; Tiffin et al., 2022). Researchers pose that 14 million tons of microfibers from textiles are released into the world's oceans yearly accounting for roughly 35% of the world's MP pollution (laundering MPs making up about 93.7% of all textile microplastics) (Allen et al., 2024; Wang et al., 2024). MPs are an enduring environmental contaminant with conservative estimates of their lifetimes measured in centuries(Chamas et al., 2020). Fortunately, existing water treatments have shown high efficacy (>95%) in removing MPs from water, but they remain co-located with sludge (Azanaw et al., 2022; Carr et al., 2016; Casoli and Rumkumar, 2020; Freeman et al., 2020; Talvitie et al., 2015). The small size and heterogeneous composition of MPs make purification a significant challenge hindering recycling and remediation efforts. In addition, continued environmental breakdown of MPs has led to 'nanoplastics', which can escape existing filtration technologies (Bové et al., 2019; Chamas et al., 2020; Hopewell et al., 2009; Schmaltz et al., 2020). Of particular concern, there is growing evidence for long-term impact on the health of human beings, with measurable levels of MPs found in blood and tissue, even in fetal tissue (Leslie et al., 2022; Simon et al., 2019)Thus, the development of isolation schemes that purify water are needed to help solve the growing proliferation of MPs in aquatic environments.

Currently, most industrialized nations regulate and maintain water quality using large industrial scale purification plants(Carr et al., 2016; Casoli and Rumkumar, 2020; Gies et al., 2018; Hossain et al., 2020; Murphy et al., 2016). Such plants ensure that drinking water is safe for human consumption and that wastewater doesn't present an ecological or human health hazard when emitted into local hydrological systems. Studies have shown that the filtration technologies used by these plants have high, sometimes as much as >99.9%, separation efficacy for MPs (EPA, 2003; Sun et al., 2019; Talvitie et al., 2015; Tiffin et al., 2022). However, these separated MPs are commingled, both with many types of plastics, but also biosolids from marine environments (Ben-David et al.,

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2021; Lares et al., 2019; Liu et al., 2020; Padervand et al., 2020). As such, targeted site applications (such as at the washing machine effluent into the wastewater drain) where collections of MPs exist in relatively high quantities and with lower secondary contaminant concentration, are an area of intensive academic and industrial research.

In recent years, several filters have been proposed to reduce MP emission in laundry effluents at the individual consumer level (Akarsu and Deniz, 2021; Li et al., 2022; Luogo et al., 2022). These technologies can largely be described as either porous bags or solid filters which can contain MPs inside, while being permeable to water, or as pronged balls designed to entangle MP fibers in their geometric structure during the wash cycles (Li et al., 2022). Alternatives, such as in-line filtration and adhesive technologies, have yet to be comprehensively integrated into new laundry machines at the commercial level (Akarsu and Deniz, 2021; Luogo et al., 2022). For in-line filtration, the required regular maintenance and the continued issue of commingling of MPs means that the remediation of such household level waste remains cost-ineffective.

To consider MP collection in real dispersions, pressure sensitive adhesives (PSAs) have demonstrated reasonably efficient extraction and purification of MPs from aqueous media (Chazovachii et al., 2021; Rieland et al., 2023). Previous efforts have shown that, under pure water conditions, capturing efficiencies of >90% can be realized using poly-2-ethyl-hexyl acrylate (PEHA) PSA (Chazovachii et al., 2021). Proposing an adhesive as a binder for microplastics in laundry machines is challenging because capturing efficiencies can also be impacted by the chemicals in detergents. Previous research has already shown that impurities such as salts and clays have reduced capturing efficiencies in aqueous systems (Rieland et al., 2023).

A few ingredients found in commercially available laundry detergents that could interfere include glycerol (solvent), sodium citrate (pH adjustment and softener), and tergitol (a non-ionic surfactant) among hundreds of others. The detergents and softeners clean the soiled clothing that can contain oils, sweat, blood and fecal material that may desorb from clothing. These additives could also adsorb onto adhesives which may impact the affinity of polyacrylates to bind with MPs (Alperstein and Knani, 2017; Gulmez and Atakisi, 2022; Kiki et al., 2022; Silva et al., 2018; Snell, 1942; Taraborelli and Upton, 1975; Xue et al., 2015).

Here, a combined modeling and experimental effort probed disparate interactions among a polyacrylate adhesive, MPs and detergent additives (glycerol, sodium citrate, and tergitol), and determined correlations between poly-2-ethl-hexyl acrylate adhesive (PEHA) binding potential and laundry additive interferences. Each additive of interest will be observed individually to glean what limitations they may have on PSA efficacy during MP capture; this will grant insight into how, generally, an array of additives may impact PEHA adhesion. Adhesive effectiveness in dilute additive systems will be probed via MP counting from imaging and WoA calculations.

2. Experimental methods

2.1. Materials

92k poly-2-ethylhexyl acrylate (PEHA) adhesive dissolved in toluene was purchased from Sigma Aldrich, and rotary evaporated to remove toluene solvent. 950k PEHA was synthesized from a procedure from Chazovachii et al. (2021) using 2-ethylhexanol and sulfuric acid (H_2SO_4) from Millipore Sigma, and polyacrylic acid (1033 kg mol^{-1}) from Scientific Polymer Products (Chazovachii et al., 2021). Tetrahydrofuran (THF) solvent and glycerol, trisodium citrate, and tergitol 15-S-9 detergent additives were acquired from Fisher Scientific. These detergent additives were purchased to consider a broad array of additives that could impact polyacrylate adhesion. Borosilicate glass substrates (25 by 75 by 1 mm) for microplastic capture were acquired from Fisher Scientific. nylon-6 powder microplastic (30-μm) was purchased from Goodfellow Cambridge Ltd. and Polyethylene terephthalate (PETE) particles were formed from soda bottles via grinding in a Vitamix® blender. 10 g MP were blended in 10 g water for 2 min, filtered in a 100-μm sieve, then dried to produce generally larger and more polydisperse particles about 100–1100 μm in size.

2.2. Adhesive preparation and coating on glass slide substrate

A 2% w/v adhesive solution was prepared with a bimodal mixture of 0.1g 92k and 0.1g 950k Poly-2-ethylhexyl acrylate (PEHA), dissolved in 10 mL THF. We found experimentally that this combination of resins was functionally more stable when deposited on a substrate and dispersed in water and migrated less during water exposure while still capturing microplastics (Rieland et al., 2023). Each resin mixture was shaken vigorously, then heated to 60 °C for 10 min to promote spray-ability from a AGPTEK Mini Airbrush (Amazon) onto a 25 × 25 mm area of labelled borosilicate slides (taped off using masking tape). To lessen MP accumulation along the edges, 2 mm of each edge of the square section was taped off. The resin was loaded into the airbrush cartridge and air was forced through the brush, coating the substrate with a thin mist. Each slide was spray-coated with adhesive until a coating mass of ~30 mg (after drying for 24 h to evaporate THF) was achieved (Rieland et al., 2023) (SI). The exact mass of each coated glass slide + adhesive was measured before immersion in aqueous additive solutions with MP particles.

2.3. Adsorption shake tests

MP adsorption tests were done to gauge how additive exposure affects adhesive capture of MPs in simulated laundering conditions. 3% w/w additive/DI water stock solutions for glycerol, sodium citrate, and tergitol were first prepared. Glycerol solution was prepared by adding 11.9 mL glycerol to a 500 mL volumetric flask, then filling with DI Water to the 500 mL line. Sodium Citrate solution was prepared by adding 3 g sodium citrate to a 500 mL volumetric flask, then filling to the 500 mL line. Lastly, tergitol solution was prepared by adding 14.9 mL tergitol a 500 mL volumetric flask then filling to the 500 mL line. The adhesive coated slides prepared previously were then placed into 0.5% w/v nylon in 30 mL additive dispersions which amounted to about 15 mg microplastics in 30 mL additive solution. In real world laundering, these additives are usually present in low concentrations of about 1 tbs/gallon (or 0.3–0.4% v/v) due to the large dilutions during laundering (Helping Hands Cleaning Services, 2024). We used higher additive fractions 3% (w/w) to trigger interferences if there was an attraction or some competition with the adhesive surfaces. At such high concentrations, any interference can be better seen. MP binding on the coated glass slides was conducted at both 1- and 5-min exposure intervals in the MP/additive/DI water suspensions.

Capturing was limited to short exposures because, unlike previous polyacrylate MP capture studies that were conducted in DI water (Chazovachii et al., 2021; Rieland et al., 2023), the stability of resins can be reduced by the resin swelling caused by laundry effluents. After 1- and 5-min exposures to the 3% additive solutions on the shaker table, samples were gently rinsed to remove non-bonding MPs and set aside to dry. Potential swelling of the adhesive by the additives was also measured by tracking mass differences of the adhesive coated glass slide before and after additive exposure. No effort was made to perform combinational experiments combining additives or sequentially exposing additives in different sequences, although that could influence binding also. Samples for each exposure condition were collected in triplicate.

Following immersion, the dried samples were analyzed by analytical optical microscopy. Images were taken using a fixed imaging protocol to account for particle stratification in the dispersions using a Nikon Eclipse light microscope (5× ocular). Nine images were taken per glass slide in a 3 × 3 grid pattern to yield a representative view of MP binding. ImageJ allowed for the images to be analyzed from a grey scale imaging pattern quantifying % surface area coverage (% SAC) using a thresholding algorithm (SI).

$$\%SAC = \left(\left(\sum A_{\text{particles and clusters}}\right) / \left(9 * A_{\text{image area}}\right)\right) \times 100 \qquad \text{Equation 1}$$

2.4. Probe tack on exposed P2EHA adhesives for aqueous work of adhesion analysis

Aqueous probe tack tests were conducted to measure the work of adhesion of the PEHA adhesive in the presence of 3% w/w additive solutions. Using a TA Technologies Texture Analyzer, 0.5 mL of 10% bimodal 92 K/950K adhesive solution in THF was deposited onto a 25-by-25 mm section of a glass slide and allowed to dry overnight. nylon and PETE probes with 0.5 mm diameter contact were affixed to the texture analyzer and force (N) vs displacement (mm) was measured after probe contact with adhesive coated glass slides submerged in separate 3% solutions of DI water, and solutions of citrate, glycerol, and tergitol. Work of adhesion (N/m) was determined by calculating the area under the Force v. Displacement curve over the probe cross sectional area (SI).

3. Modeling methods

3.1. Structure generation

PEHA strands were generated using a polymer generation code (see SI for further details). Each polyacrylate strand was made from a racemic mixture of 2-EH acrylate sidechains. Each polymer strand was relaxed *in vacuo* in 1 ns CHARMM-GUI simulations. For MP surfaces CHARMM-GUI generated polymer strands of PETE and nylon of sufficient size to approximate macroscopic properties, which were annealed into MP particles of ~50–100 nm^3 in size, in 1 ns runs (see SI for more details).[47] These surfaces are representative of pristine MP models, lacking *in situ* changes or modifications that may occur in the environment. Sodium citrate, glycerol and tergitol structures were generated by hand, using Avogadro, and similarly relaxed for 10 ps.

3.2. Force field assignment

The CHARMM general force field version 4.0 (cgenff) was used to model the interactions, as prior work had parameterized force fields for similar atom types (Alberga et al., 2014; Alexiadis and Mavrantzas, 2013; Cheung et al., 2009; Huang et al., 2010; Mayo et al., 1990; Moreno et al., 2010; Poelking and Andrienko, 2013; Schwarz et al., 2013). Force fields were assigned to bond types using the Match program (Yesselman et al., 2012). As previous work tested cgenff for the modeling of polymers and contaminants, no further validation of force field assignment was done. With the interest on contaminants in laundry effluent, the modeling focused on laundry modifiers and additives like sodium citrate, glycerol and tergitol, which are all found in fabric softeners.

3.3. Determination of a work of adhesion ($WoA_{(aq)}$) in contaminated aqueous conditions

Separating the elements of a simulated adhesive into three interaction "boxes" yields a computationally efficient method to find the $WoA_{(aq)}$:

$$WoA_{(aq)} = \gamma_{adhe-water} + \gamma_{plas-water} - \gamma_{adhe-plas} \qquad \text{Equation 2}$$

where γ is the interfacial interaction energy for the interface between the listed components in separate simulations, normalized for area. However, the work cycle becomes more complex for simulations containing water and other additives, as the macroscopic properties of aqueous solutions can change dramatically depending on the dissolved ions and molecules. As such, a new contaminant work cycle was rederived to determine the change in $WoA_{(aq)}$ for any one dissolved molecule (SI). Four independent simulations must be performed to determine the WoA at a given concentration for a contaminant ($WoA_{(\%contaminant)}$), and an additional empirical factor to account for the change is the surface tension from pure water to a solution is added. As the pure water simulations remain constant, accounting for different concentrations of contaminants or different contaminants only requires two additional simulations for any of these changes. A full derivation of the new $WoA_{(\%\ contaminant)}$ can be found in the SI.

3.4. Statistical validation

An important concern when analyzing MD simulations is whether sampling multiple polymers of the same composition results in meaningful averages for their properties. Another possible statistical issue is clustering of pendant groups on the polymer, leading to structures that look more like block copolymers than random copolymers. To avoid these issues in simulations, six versions of each racemic 2-EH composition were independently generated using an algorithm that distributed the different chiral side chains randomly throughout the structure. These structures are kept at a fixed molecular mass of 300 monomers. Each of these six chains was then independently equilibrated ten times for 25 ns, for the aqueous and MP models. After these equilibrations, 5 ns trajectories with a frame taken every 200 ps were used to determine each average value. This resulted in 60 simulations for each %composition, which were then averaged to determine the $WoA_{(aq)}$. Error was quantified as the standard deviation of the combined simulation data for each data point. Outliers were determined using the Q-test and omitted from reported results. Further description of methods can be found in the SI.

4. Results and discussions

The output from the characterization and physical binding experiments is provided with some general insights from modeling similar compositional phase space.

4.1. Laundry additives interact with adhesives by swelling them

Even after rinsing and drying, all aqueous additive solution exposures resulted in gravimetric increases in PEHA resin mass, while exposing adhesives to pure DI water gave virtually no absorption. Sodium citrate showed the most absorptive which may be explained by the higher solubility of ionizable molecules in water (O'Callaghan et al., 2010; Santos et al., 2009), but all the additives swelled the acrylate resin.

Functionally, swelling likely reduces the resin Tg, increases resin mobility on the substrate, and affects the resin tackiness for its affinity for other microplastic particles. Other studies have showed decrease in Tg and surface tension and increases in tackiness for resins exposed to both ionic and non-ionic surfactants (Baglioni et al., 2022; Sarkar and Jayaram, 2018; Zhang et al., 2023) Atomistic simulations of polymer/additive interactions (Fig. 2) reveal additional details that complement the swelling observations in Fig. 1.

The images in Fig. 2 show representative interactions of citrate, glycerol, and tergitol with 2-EHA, revealing distinct differences in surface interactions. The pure water control in Fig. 2A shows compact, roughly spherical 2-EHA (white spheres simplified for PEHA) that are largely non-polar given the molecular composition of 2-EHA. This non-polarity results in minimum interactions with the strongly polar pure water environment (cyan). In Fig. 2B and C, the interactions between citrate (green), glycerol (purple) and PEHA (white) suggest pockets of additives interacting on the PEHA matrix. This compares to tergitol (pink) in Fig. 2D where the contaminants more comprehensively coat the surfaces of PEHA. Similar responses are noted for the simulated additive interactions particularly for tergitol on the microplastic particle

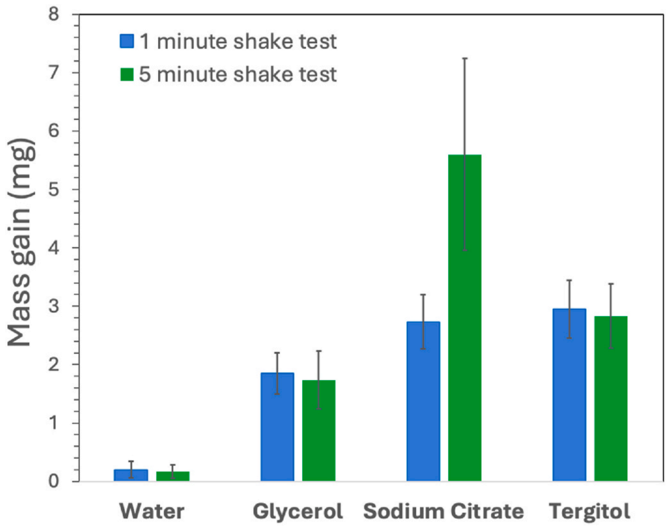

Fig. 1. Relative mass gain of PEHA after 3% dilute additive exposure with error bars representing _ ± 1 standard deviation. All the additives show significant mass gain ($p < 0.05$) at both shake test times, relative to DI water as a control and are essentially invariant with exposure time comparing 1 and 5 min of exposure with the exception of sodium citrate.

surfaces (SI). These modeling results support the experimental swelling and suggests additive binding on the adhesives, blocking other surface sites for microplastic binding. They are also in line with previous studies that suggest fouling behavior of tergitol with PEHA (Rieland et al., 2023). From modeling results, an additional concern is that if the resin affinity for a surfactant is stronger than that for microplastics, the surfactant might act as blocking agents and prevent continued MP adsorption due to that fact that surfactants are known for their great wettability (Jing et al., 2024; Zhang et al., 2023).

4.2. *Microplastic capture by adhesives in the presence of additives as interferences*

MP binding tests give a more holistic picture of how PEHA/additive interactions impact nylon and PETE binding to the adhesive surface (Fig. 3). Approximations for binding efficiencies were conducted by calculating % area of coverage. PETE particles are much larger than nylon, yet a similar capturing phenomenon was seen for both MPs where binding is observed in water, glycerol and sodium citrate, but is dramatically reduced in tergitol. These results support observations that the surfactant solution acts as a blocking agent by coating both resin and particulate surfaces, preventing their bulk attachment underwater. Erosion of the PEHA matrix is also observed with tergitol exposure as thinning and crazing of the PEHA matrix causes globular areas where no adhesive is present (Fig. 4H).

4.3. *Adhesive physical properties in the presence of additives via work of adhesion measurements*

Probe testing in static aqueous solutions (3% w/w in DI water), DI Water and air to compare adhesive strength between additives and

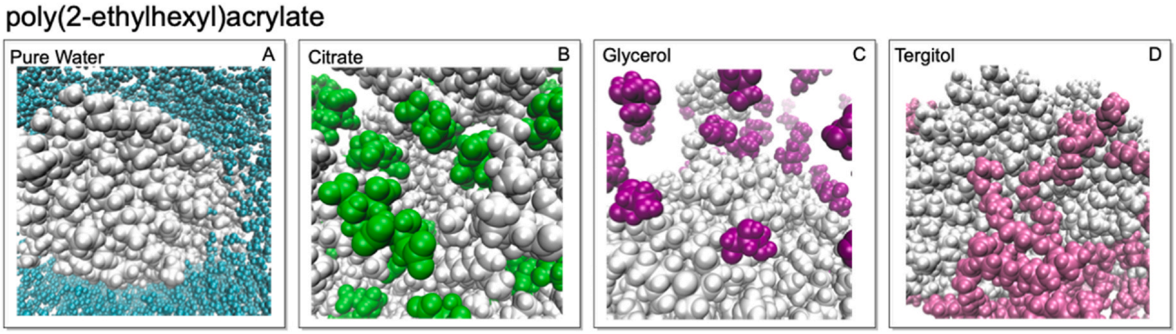

Fig. 2. Qualitative examination of water molecule (A), citrate (B), glycerol (C), and tergitol (D) interaction with 2-EHA at high concentrations. Water molecules in B-D were removed for clarity.

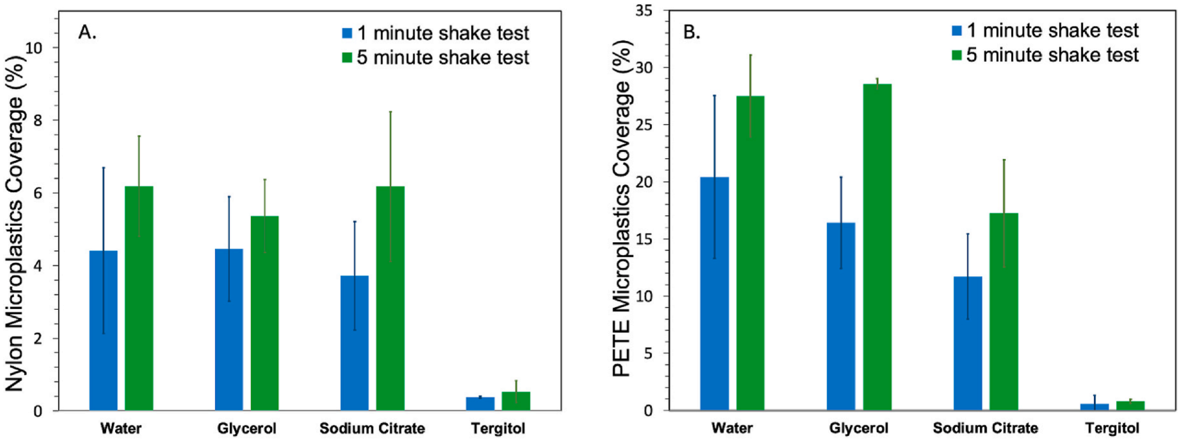

Fig. 3. Total area of coverage for A) nylon (30 μm) and B) PETE (100–1100 μm) on a 3 × 3 grid formed on adhesive-coated glass slides. % Coverage of bound particulates was found for shaken dispersions of DI Water, glycerol, sodium citrate, and tergitol also containing particles for 1 and 5 min. MPs were collected at the two time points and % coverage on the slide was used to determine capturing efficiency. Tergitol exposure results in statistically reduced ($p < 0.05$) microplastics coverage at 1 and 5 min compared to water for nylon and both time points for PETE particles. The other additives were not statistically significant from water.

nylon or PETE probe surfaces (Fig. 5). Experimental results show that work of adhesion (WoA) for submerged PEHA in the aqueous solutions were lower than that in air by a factor of about 2. Similar adhesive response was observed using the nylon probe with high work in air relative to those submerged in DI water, citrate and glycerol solutions. When the Nylon probe was exposed to the tergitol solution, there was almost a complete elimination of the work of adhesion. We attribute the more pronounced reduction to a larger interference and a higher affinity for tergitol to the nylon particles and binding seems to be kinetically faster or simply more efficient. The probe tack results in tergitol are consistent with MP capture tests that show reductions in nylon/PEHA interactions in tergitol.

Most WoA values for PETE are comparable to those observed for nylon. WoA reductions of 38.3, 61.3, 39.9, 54.5% were seen for DI Water, sodium citrate, glycerol, and tergitol respectively when compared with dry adhesion in air, indicating reduced attachment force when submerged in the aqueous environments. PETE results for tergitol suggest though that adhesive interference is not as notable as nylon interferences and that adhesion properties in tergitol are comparable to citrate, glycerol, and DI water. While PETE/tergitol results do not align with MP capture tests (Figs. 3 and 4), which show low PETE capture in tergitol, PETE fragments are plate-like and bigger than the nylon particles. We anticipate that particle size is a factor inhibiting binding to additive loaded adhesives. In addition, during MP capture tests, longer exposure times in tergitol (1 and 5 min), and high adhesive erosion from turbulence causes large increases in PEHA-tergitol interactions, reducing capture efficiency for PETE. Regardless, MP capture data show that tergitol inhibits binding to both nylon and PEHA. Based on modeling results (Fig. 2D), we can postulate that tergitol coats adhesive surfaces and prevents their wetting and subsequent attachment of particles.

WoA vs Concentration curves were generated using the CHARMM general force field (cgenff) to model interactions between individual molecules (Fig. 6, more details are found in the SI) and to observe limitations of higher concentration aqueous dispersions and solutions. Because higher concentrations increased molecular interactions between additives and polymers, WoA values, and thus adhesive behavior, is impacted. Computational data shows that each of the tested contaminants with nylon and PETE demonstrate an exponential decay for WoA with concentration. As suspected, high concentrations of each of the contaminants have significant and negative impacts on the WoA for both PETE and nylon, especially for tergitol. glycerol and sodium citrate

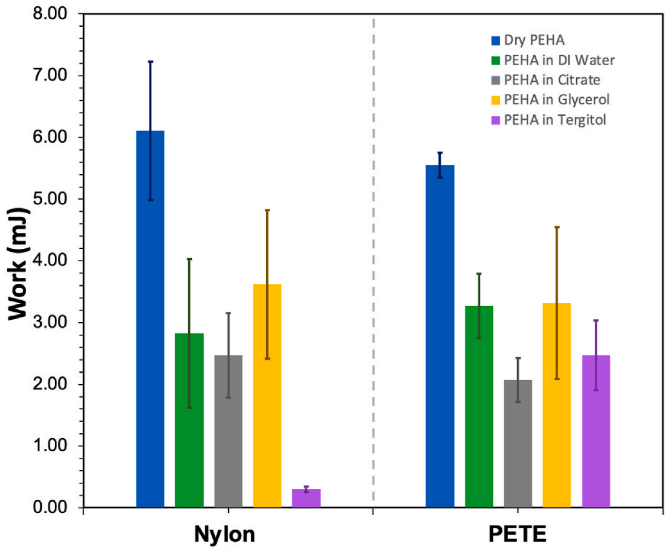

Fig. 5. Experimental WoA$_{(aq)}$ values assessed as a probe tack-measurement for PETE and nylon probes at dry conditions (blue) and in 3% v/v static, dilute solutions of DI Water (green), glycerol (grey), sodium citrate (yellow) and tergitol (purple). There is a cross-sectional area for the probe, a force at failure and a strain at from failure, and from that, one can resolve work. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

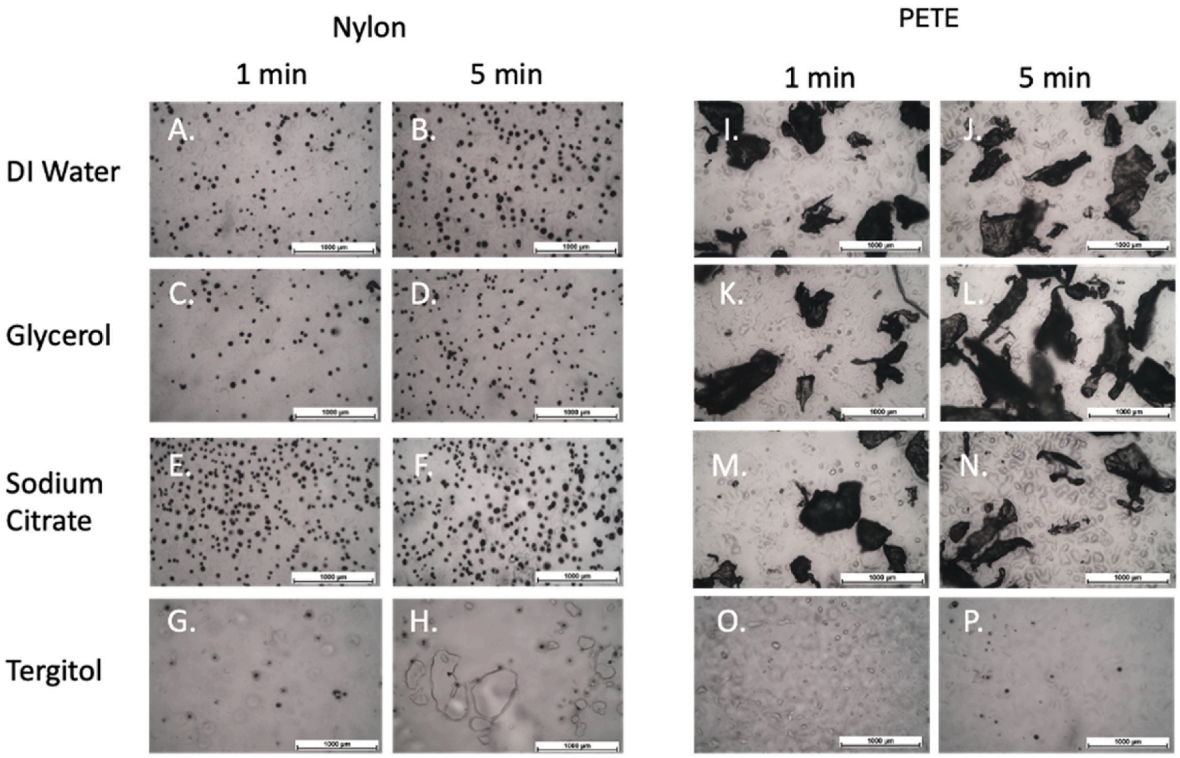

Fig. 4. Optical Imagery of MPs bound on a PEHA coatings captured after 1 and 5 min in DI water, glycerol, Sodium citrate, and tergitol (top down). Images were taken with a 5× optical lens.

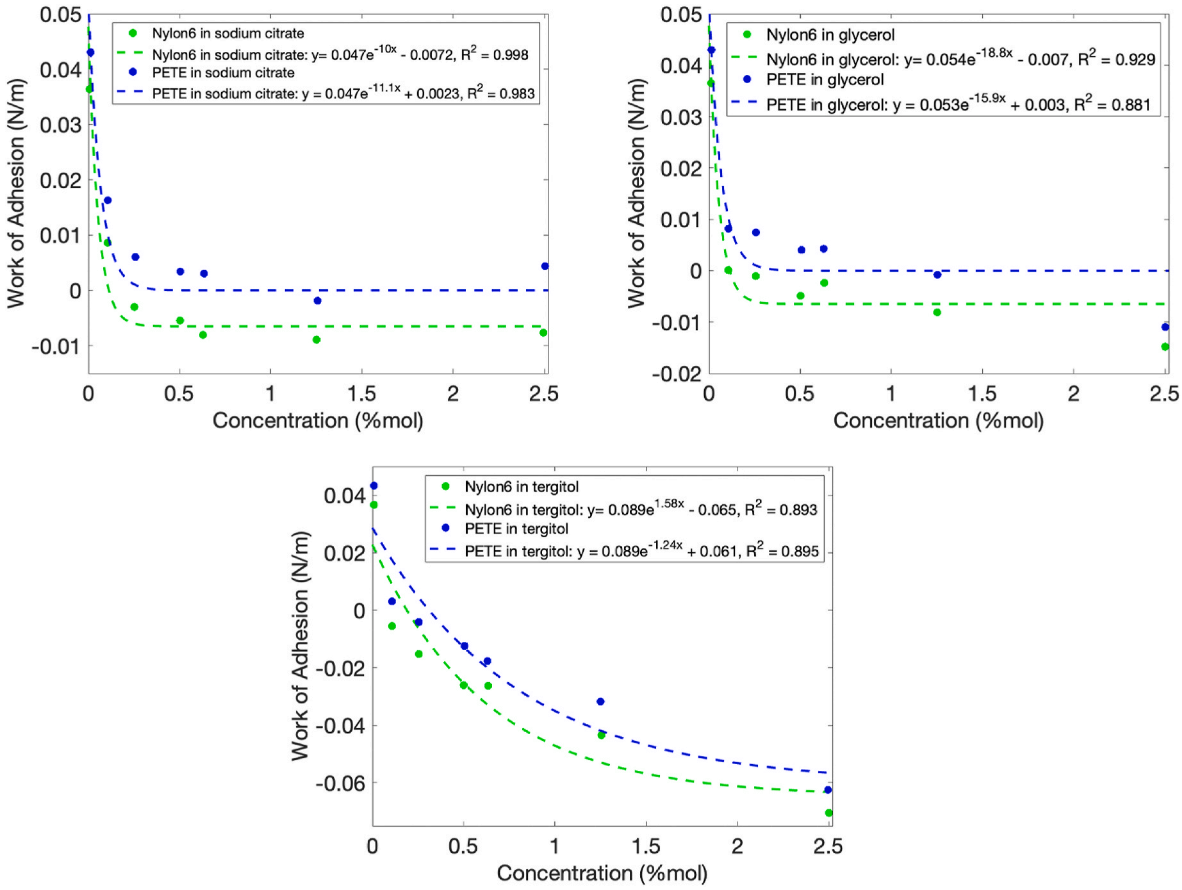

Fig. 6. Computational WoA plots vs. concentration for A) Sodium citrate, B) glycerol and C) tergitol, with an exponential decay line of best fit.

have a sharper initial reduction in WoA, but tergitol is strongly inhibitory of adhesion as even at 0.1 mol%, both nylon and PETE no longer adhere to PEHA. The relationship between concentration and adherence is further proven by negative WoA results which are synonymous to unstable adherence conditions (Comyn, 2020; Popov, 2020). Both sodium citrate and glycerol have very rapid decaying curves indicating that maximum impact on WoA occurs at ~0.5 mol%. Interestingly, tergitol has yet to reach its maximum impact even at 2.5 mol% which indicates strong inhibition.

Modeling results for WoA (Fig. 6) are comparable to experimental results (Fig. 5) which show strong an inhibition with tergitol and much less nylon adherence to the adhesive. Nonetheless, experimental capturing results will not directly correlate with real laundering conditions. For one, experimental WoA measurements for were done under non-turbulent, static conditions. Turbulent shear has an erosive effect on the adhesive, complicating our quantification of particulate binding by visual monitoring. In addition, while MP capture tests used modest shearing conditions, those tests were short, much shorter than a typical laundry cycle (30 min–1 h). Nonetheless, the predicted and measured *in situ* effect indicates that PEHA captures MPs in laundry effluents, though likely with minimal efficiency over an unmodified filter that accounts for changes in adhesion in the presence of detergent additives.

There remain a number of open questions such as how one might adapt new generations of washing machines or retrofits to existing machines to accommodate the capacity to collect MPs over time. If the resins could be tuned for maximum adsorption for the most commonly shedding microplastics in laundry, that would be a great start. If the adhesive substrate offers promise for collecting and isolating microplastics from the washer, details to address the overall robustness and functionality will need to be considered including extending the stable functional time the resin can be exposed in the wash cycle, increasing its resistance to erosion and abrasion in the turbulent flow of the washing, rinse, and spin cycles, and maintaining the adhesive quality of the resin for multiple wash cycles, particularly in the presence of dirt, soaps and detergents, surfactants and fabric softeners, and in areas where different waters are functionally used. Overall, if the capture system evolves into a fragment similar to a dryer sheet used with each wash cycle, that seems possible. But a more durable and functional adhesive system capable of capture over multiple wash cycles probably has a lower environmental footprint in the long run.

5. Conclusions

A combination of experimental and modeling work assessed microplastic capture by adhesives in the presence of three common additives in soaps and detergents: glycerol, sodium citrate, and tergitol (3% w/w in DI water). The adhesive evaluated was a common ethyl hexyl acrylate resin. Experiments show that all additives interfered with adhesive mediated binding for MP capture, due primarily to molecular blocking of the adhesive resin and swelling. These surface interactions were reinforced by modeling efforts that showed that there was a driving force for additives to block adhesives from the microplastic particles. Significant reductions in binding are observed for tergitol exposed adhesives. In addition, large decreases in experimental Work of Adhesions (94.9% for nylon and 54.5% for PETE) for tergitol exposed samples support low binding efficiencies of <1% SAC for both nylon and PETE MPs onto PEHA. Overall, using slides, optical measurements, and rapid sampling to assess micro plastic adsorption grants insight into binding characteristics for MPs in additive exposed systems, but further optimization is required either by modeling or by further experimentation to learn more about implementation in laundry applications.

CRediT authorship contribution statement

Tolulope D. Lawal: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Timothy Jugovic:** Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Griffin Josephs:** Software, Formal analysis, Data curation. **Paul M. Zimmerman:** Writing – review & editing, Software, Methodology, Funding acquisition, Conceptualization. **Brian J. Love:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Brian Love reports financial support was provided by National Science Foundation. Tolu Lawal, Tim Jugovic, Griffen Josephs, Paul Zimmerman reports financial support was provided by National Science Foundation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2024.125372.

Data availability

Data will be made available on request.

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