Environmental weathering transforms plastic pollution

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The prevalence of plastics in our daily lives is reflected by their ubiquity in nature. Jeffrey M. Farner from the FAMU-FSU College of Engineering, details how environmental weathering transforms plastic pollution

Due to use, improper disposal, and environmental transport, plastics are found globally, including in unpopulated locations. This pollution ranges from intact discarded items large enough to be choking hazards for marine life to particles at the nanometer scale. These smallest particles have been observed to translocate into animal tissues, raising concerns about toxicity. The concentrations of plastic particles vary widely, as do the morphology and other characteristics, but they exist.

Environmental stressors lead to transformations

Though often discussed as a single material, plastics are a broad classification of products. Further complicating the situation, particles in the environment are exposed to environmental stressors, leading to plastic weathering. Factors like ultraviolet radiation (UV), temperature, abrasion, and shear stresses cause physical and chemical transformations. These result in particles that are generally smaller, more irregularly shaped, and more oxidized than the initial product. (1,2)

Plastic weathering is a function of both the material itself (e.g., polymer, morphology, additives) and the environmental conditions (temperature, UV exposure), and these new particles may behave quite differently compared to the initial engineered plastic. Additionally, the associated changes in hazards arising from weathering still need to be clarified.

Nanoplastic size influences behavior

Particle size influences fate and transport. We have shown that interactions with natural organic matter (NOM) differ for 28 versus 220 nm polystyrene nanoplastics (PSNPs). (3) Using carboxylated polystyrene spheres as models for weathered nanoplastics, we observed aggregation in the presence of NOM and calcium to simulate saline waters. The presence of either alginate or humic acid increased the rate of PSNP aggregation for both particle diameters. Due to bridging, PSNPs were incorporated into NOM-PSNP heteroaggregates, and this effect was more pronounced with suspensions of 220 nm PSNPs.

Curiously, in natural saline water samples, 220 nm PSNPs aggregated more slowly than their smaller counterparts. We hypothesize that the mixture of NOM fractions present may confer stability that is not easily observed in simplified systems. Overall, these results highlight the size-dependency of particle-NOM interactions and the importance of the system itself in which plastic pollution is found.

Surface chemistry plays a role

Changes to the particle surface chemistry can also influence fate and transport. The weathering of polyethylene microspheres due to UV and shear results in fracturing and oxidation. (2) In the context of water treatment, where particle removal is performed via coagulation and flocculation, we observed that increased oxidation of a plastic surface results in greater interactions with coagulant and that removal rates were greater for the smaller, weathered polyethylene particles than for the initial microbeads. These results highlight that the behavior of plastic pollution is impacted by, e.g., size, morphology, and oxidation rather than an intrinsic property solely dependent on the type of material.

Same starting material, different impacts

In addition to influencing fate, weathering-induced transformations can influence the ecotoxicological impact, or hazard, associated with exposure. Recently, we have observed that the same starting material – in this case, polystyrene – will impact sewage sludge in an anaerobic digestor differently based on the path of weathering. (4) Four suspensions of PSNPs were created from the same polystyrene production pellets – spherical, weathered spherical, irregularly shaped, and weathered irregular-shaped particles. Weathering to both spherical and irregularly shaped particles was performed through a combination of heat, UV, and mixing. It resulted in the addition of oxygen-containing functional groups (hydroxyl, carbonyl, and phenolic) at the particle surface. These four suspensions were then introduced at 25 or 150 µg/L to anaerobic digestors to assess how PSNPs interact with microbial communities.

While little change was observed when microbial communities were exposed to 25 µg/L, the addition of 150 µg/L inhibited methane generation, which was attributed to oxidative stress. Irregularly shaped PSNPs (with or without additional weathering) resulted in greater inhibition (up to 20%), which may be due either to their morphology or to an increase in bioavailability. Reactors were sampled for the presence of antibiotic resistance genes (ARGs) and mobile genetic elements, both of which increased in the presence of all PSNPs compared to controls. The abundance of ARGs was further increased with irregularly shaped PSNPs versus spherical and with weathered PSNPs versus unweathered.

These results demonstrate that microbial communities will react differently to the presence of nanoplastics based on particle morphology and oxidation despite originating from the same plastic product. This suggests that the weathering pathway or the history of the plastic itself is important and that effects may be path-dependent.

Weathering complicates our understanding of plastic pollution

Ultimately, this work presents a complex picture in which plastics should not be considered a monolith but rather a classification of pollutants with polymer type as one characteristic. Other similarly important characteristics include particle size and morphology, surface modifications (which can consist of oxidation, surface roughness, sorption, or microbial colonization), and matrix additives. These characteristics will be influenced by the context in which the particles are formed and exist. Differing water chemistries may result in certain characteristics being emphasized over others (e.g., size versus morphology or surface oxidation versus polymer type). Thus, understanding the impact of plastic pollution necessitates identifying the primary drivers of fate, transport, and hazard in a given system.

References

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