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Viewpoint

Color: An Important but Overlooked Factor for Plastic Photoaging and Microplastic Formation

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Plastic pollution has become an increasingly serious environmental issue of global concern. Approximately 9200 million tons of primary plastics were produced between 1950 and 2017 (United Nations Environment Programme (UNEP) 2021). Because of different manufacturing purposes, plastics of various *colors* are widely available in our daily life. *Colors* are added to plastics through pigments to obtain plastic products that are more attractive and in line with actual usage needs. Pigments can also act as light-shielding agents to absorb part of ultraviolet (UV) light to prevent or delay photodegradation, thereby extending the service life of plastic products.

Once exposed to the natural environment, plastics readily undergo various aging processes, including sunlight irradiation, wave and wind stress, mechanical abrasion, thermal oxidation, and biodegradation. Among them, sunlight irradiation is considered to be the primary cause of plastic aging, which tends to induce polymer chain reactions and chain scission, leading to plastic fragmentation into microplastics. Photoaging generally causes changes in *colors* of plastic polymers. Conversely, the *color* of plastics *per se* will also significantly affect the absorption of sunlight, and plastics of different *colors* absorb light of different wavelengths and energy. In this Viewpoint, we argue that *colors* of plastics may play key roles in the plastic photoaging, microplastic formation, and subsequent environmental effects of microplastics, which have been overlooked in previous research.

■ EFFECT OF COLOR WAVELENGTH

Plastic products can be divided into seven categories according to their chromatic *colors*: brown, red, orange, yellow, green, blue, and purple (black, white, and gray are achromatic *colors*). For plastics of different color systems, a different *color* wavelength may affect the plastic photoaging by influencing its solar absorbance and UV transmittance. Generally, in the visible-light region, red or yellow pigments with longer wavelengths may absorb short-wavelength light with higher energy, while blue pigments absorb long-wavelength light with lower energy. The corresponding light energy transmitted to the blue plastic is consequently higher than that transmitted to red or yellow plastics, which makes the photoaging more intense. UV light has the shortest wavelength located far away from the red visible spectrum and is more easily absorbed by red pigments with the longest wavelength. Therefore, it is hypothesized that the longer the *color* wavelength, the stronger the light absorbance, the lower the UV transmittance and, thus, the lower the photoaging rate will be (Figure 1). Because blue plastics cannot effectively absorb UV light, they age faster in the sun, and a higher proportion of bluish microplastics is often found in the environment, especially toward the smallest sizes.[1]

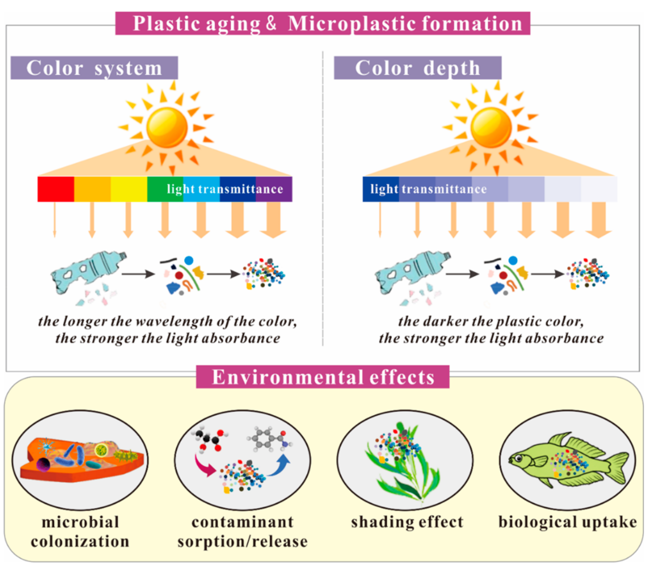

Figure 1. Effect of plastic color of different color systems and different color depths on plastic aging and microplastic formation and the subsequent environmental effects.

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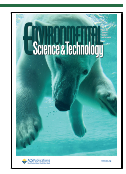

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In contrast, fragments of reddish plastics usually occur in larger sizes than the bluish ones in the field.

However, most documented studies are limited to using white or transparent plastics, while there are only few reports on the differences in photoaging between various colored plastics.[2] Hence, most previous studies have neglected that *colors* may be an important factor interactively influencing plastic aging and microplastic formation.

■ EFFECT OF COLOR LIGHTNESS

For plastics of the same *color* system, the primary factor that affects the UV transmittance of plastics is the depth of *color*. Since the *color* covers the transparent layer, the light will be greatly attenuated when passing through the colored sample, in which case the dark color can be more protective. The best description of *color* depth was provided by the L^* value (i.e., lightness) of the CIELab system. It is hypothesized that the darker the plastic *color* (the smaller the L^* value), the stronger the light absorbance, the lower the UV transmittance and, thus, lower photoaging rate (Figure 1). For example, the pigment carbon black ($L^* = 0$) has the highest light absorption, which can effectively prevent UV light from penetrating into the polymer, thereby inhibiting the aging of plastic products, while white ($L^* = 100$) plastics age relatively faster in sunlight.

Photoaging processes in turn will cause changes in plastic *color* (especially lightness), which can help indicate the exposure time of plastic particles in the environment. During extended solar exposure, the *color* of plastics first gradually changes to light *colors* (discoloration or whitening) and then further changes from white to yellow or amber (yellowing and tanning, respectively) because of weathering.[1] Such coloring effects are mainly ascribed to the generation of chromophore products from the oxidation of microplastics or products containing quinonoidal structures generated from the oxidation of phenolic antioxidants.[3] Generally, the *color* deepens as the weathering time is prolonged. Therefore, the *color* changes may indicate the degradation stages of plastic debris to a certain extent and be potentially used as proxies of their exposure time in the environment.[1]

■ SUBSEQUENT ENVIRONMENTAL EFFECTS

In addition to their direct effects on the photoaging of plastics as discussed above, *colors* may further affect the colonization of microorganisms on microplastics, the adsorption, release, and degradation of pollutants associated with microplastics, and the biological toxicity of microplastics. Considering the bactericidal effect of UV radiation on common bacteria and viruses as well as the changes in plastic particle size and surface functional groups caused by photoaging, it is suggested that the *color* can affect the UV radiation and physicochemical properties of the microplastic surface, thereby affecting the community structure and functional diversity of microorganisms living on microplastics. A study has shown that biofilms colonizing blue microplastics appear to have a higher functional diversity than those colonizing transparent or yellow microplastics due to different light availability of specific pigment content/color of microplastics.[4]

Color of pigmented plastics should also be considered for an assessment of the fate of pollutants adsorbed on microplastics through phototransformation or dissolved and released from microplastics themselves during photodegradation. For example, sunlight can regulate the release of cadmium from the aqueous phase of cadmium-containing colored microplastics.[5] Furthermore, the *color* of microplastics may potentially affect their ingestion by aquatic organisms because some organisms, such as gobies, are visual predators and are prone to ingest microplastics with *colors* resembling their prey.[3] The shading effect of colored microplastics on algae, which can induce growth inhibition, is still unknown and needs to be further explored.[2] Therefore, the influence of *color* should also be considered in assessing the ecological risk and toxicity of plastics in the environment.

In conclusion, given that *color* may serve as a good indicator of the age of plastics and play an interactive role in altering their degradation and formation of microplastics, *colors* of plastics must be considered in the monitoring, behavioral, and (eco)toxicological studies of bulk plastics, microplastics, and nanoplastics in the future. Regarding pollution prevention and control of microplastics in the environment, pigments with longer color wavelengths and lower lightness are recommended in manufacturing to produce plastics with high UV resistance and thus reduce the formation of microplastics and nanoplastics.

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Notes

The authors declare no competing financial interest.

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