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RESEARCH ARTICLE

Characteristic of microplastics in the atmospheric fallout from Dongguan city, China: preliminary research and first evidence

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Abstract Microplastic pollution has exhibited a global distribution, including seas, lakes, rivers, and terrestrial environment in recent years. However, little attention was paid on the atmospheric environment, though the fact that plastic debris can escape as wind-blown debris was previously reported. Thus, characteristics of microplastics in the atmospheric fallout from Dongguan city were preliminarily studied. Microplastics of three different polymers, i.e., PE, PP, and PS, were identified. Diverse shapes of microplastics including fiber, foam, fragment, and film were found, and fiber was the dominant shape of the microplastics. SEM images illustrated that adhering particles, grooves, pits, fractures, and flakes were the common patterns of degradation. The concentrations of non-fibrous microplastics and fibers ranged from 175 to 313 particles/m^2/day in the atmospheric fallout. Thus, dust emission and deposition between atmosphere, land surface, and aquatic environment were associated with the transportation of microplastics.

Keywords Microplastics · Atmospheric fallout · Dongguan city · μ-FTIR · SEM

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Introduction

In recent years, large quantities of studies on microplastic (< 5 mm) pollution in the environment have been widely carried out. Due to the small size, microplastics might be easily ingested by organisms. And multiple kinds of organisms have been reported to ingest microplastics (Laist 1997; Gall and Thompson 2015). Thus, those associated toxic chemicals, e.g., organic pollutants (Mato et al. 2001; Ogata et al. 2009; Hirai et al. 2011), heavy metals (Holmes et al. 2012; Rochman et al. 2014; Turner and Holmes 2015) absorbed from the surrounding environment, and the unreacted monomers, additives, and other ingredients in microplastics (Lithner et al. 2011; Rochman et al. 2013), are potentially exposed to the organisms. Microplastics have been proposed as one of ten emerging issues in UNEP Year Book 2014, and have been identified as an important factor leading to biodiversity loss (Gall and Thompson 2015) and pose a potential threat to human health and activities (Eerkes-Medrano et al. 2015a).

Microplastics have become a prevalent component in the global environment, including seas (Desforges et al. 2014; Ng and Obbard 2006; Thompson et al. 2004), freshwater lakes (Eriksen et al. 2013; Faure et al. 2012), rivers (McCormick et al. 2014; Moore et al. 2011; Morritt et al. 2014), and terrestrial environments (Jambeck et al. 2015; Rillig 2012). Recently, Dris et al. (2016) found large amounts of fibers in the atmospheric fallout, and presence of microplastic fibers was identified by μ-FTIR. However, this study just focused on the microplastic fibers. As we all know, plastic debris can escape as wind-blown debris from landfills (Barnes et al. 2009). Unfortunately, less attention was paid to the microplastics from dust emission and deposition, which play an important role in the physical and chemical exchange process between atmosphere, land surface, and aquatic

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environment. Thus, characteristics of microplastics in the atmospheric fallout from Dongguan city were preliminarily studied by taking advantage of the air monitoring system of Dongguan Environmental Monitoring Central Station.

Materials and methods

Study area

Atmospheric fallout samples were collected from three sites of the air monitoring system in Dongguan Environmental Monitoring Central Station (Fig. 1), i.e., Site S1 (23°05′N 113°79′E) in the Laboratory middle school of Dongguan in the Dongcheng District, Site S2 (23°06′N 113°76′E) in a waterworks in the Guancheng District, and Site S3 (23°03′N 113°75′E) in Dongguan Gym in the Nancheng District. Sample collection was conducted from October to December, specifically, 31 days from October 1st to 31st, 30 days from November 1st to 30th, and 31 days from December 1st to 31st, in 2016. Dongguan city has a population of 8,316,600 and covers an area of 2465 km^2, and there are about 0.48, 0.17, and 0.31 million people in Dongcheng District, Guancheng District, and Nancheng District in 2016, respectively.

Sampling and pre-treatment

Atmospheric fallout (dry and wet deposition) was continually sampled in each site by using a sampling device equipped with a glass bottle (30 cm × Φ15 cm, i.e., opening area is 0.0177 m^2, volume is 5.31 L) and a fixed support. There are no huge buildings around the chosen sampling sites and all the glass bottles in each site were almost 15 m above the ground. And, the bottles were required to be cleaned in an ultrasonic bath with ultrapure water prior to their use. Notably, the samples should be timely transferred in the rain days in order to prevent samples from escaping. The volumes of the samples were recorded before sample treatment, and the date as follows: 1080 mL, 475 mL, and 270 mL of the samples were collected in S1 in Oct., Nov., and Dec., respectively; 735 mL, 570 mL, and 140 mL of the samples were collected in S2 in Oct., Nov., and Dec., respectively; 1010 mL, 300 mL, and 120 mL of the samples were collected in S3 in Oct., Nov., and Dec., respectively. Then the samples would be closed and stored carefully at the end of each collection period.

All the collected samples were filtered through 1.0-μm glass microfiber filters (Whatman GF/B) with a vacuum pump. In addition, the walls of the bottles and filtration device were washed with ultrapure water and the cleaning solution was also filtered. All the matters on the filters were dried at 50 °C for 48 h and stored in Petri dishes. In order to avoid the background contamination, laboratory coats should be worn, and the filtering device and bottles should be treated by ultrasonic cleaning and heated to 200 °C for 2 h before using. Besides, the blanks are needed to verify that no extra microplastics will be added to the samples during the experimentation (Dris et al. 2016).

Visual observation and μ-FTIR analysis

Particles on the filters were analyzed by a digital microscope (Dino-Lite AM3011T) equipped with a software program DinoCapture 2.0 (Qiu et al. 2015; Yu et al. 2017). Samples

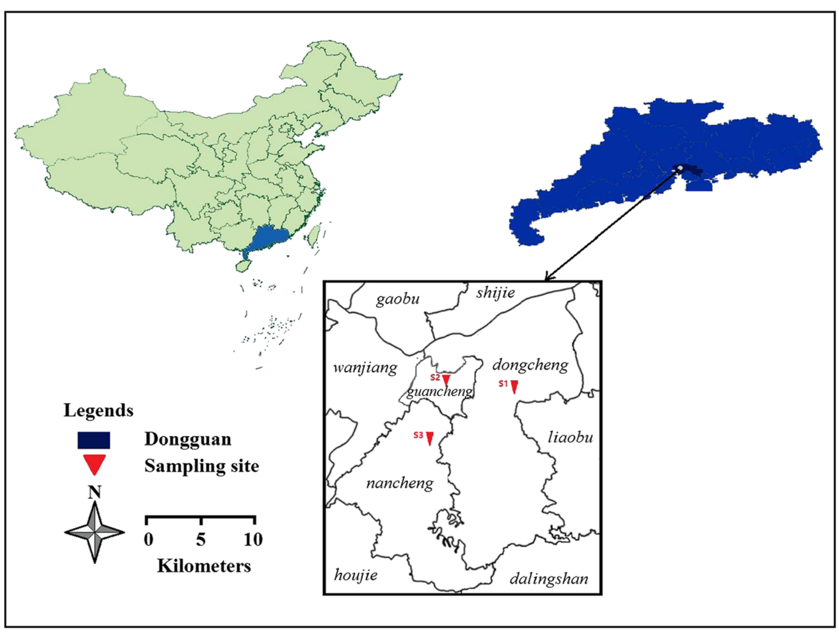

Fig. 1 Location of sampling sites from the air monitoring system in Dongguan Environmental Monitoring Central Station

were initially identified by visual observation based on the common criteria (Hidalgo-Ruz et al. 2012; Norén 2007).

In order to make a further identification for the suspected samples, μ-FTIR analysis (Vianello et al. 2013; Qiu et al. 2015) was carried out with an infrared microscope (Nicolet iN10, Thermo Fisher, USA) equipped with a Deuterated Triglycine Sulfate (DTGS) detector. Microplastics have been reported as pellets, fragments and films, and fibers. Because fiber was the dominant shape of the suspected microplastics in the atmospheric fallout samples, 20% of them were randomly selected to be detected, while all other suspected samples were detected.

Samples can be detected non-destructively and the need of sample preparation was minimal (Ojeda et al. 2009; Vianello et al. 2013). Two different surface sites of each suspected sample were detected in order to obtain higher match degrees of resulting spectra. Signals were obtained in reflectance mode and the spectral range was set at as 4000 to 500 cm^{-1}. Then, the resulting spectra would be compared with the databases offered by Thermo Fisher Scientific in OMNIC software without post-processing and transformation (Li et al. 2016; Frias et al. 2014). Notably, apart from these purely natural fibers, some fibers were made with a mixture of different materials. In identification, the chemical composition of the purely synthetic material fibers would be determined according to their higher match degrees. However, other fibers being a mixture of natural and synthetic materials would be counted as plastic fibers.

SEM analysis

Information about the particle's experiences can be obtained from the observation on the surface characteristics by using scanning electron microscopy (SEM) (Eerkes-Medrano et al. 2015b). SEM analysis on microplastics collected from sediments and water was widely carried out; however, no data were available in the atmospheric fallout. In this study, the surface characteristics of microplastics from the atmospheric fallout were studied by JEOL JSM-6510 SEM and comparison on the similarities and differences of polymers in different environments would be also carried out.

Results and discussion

Occurrence of microplastics in the atmospheric fallout

Similar to the results shown by Dris et al. (2016), fiber was the dominant shape of the suspected microplastics initially identified by visual observation. Further identification of fibers by μ-FTIR demonstrated the occurrence of microplastic fibers in atmospheric fallout in Dongguan city (Fig. 2a). Besides, foams, fragments, and films were also found (Fig. 2b–h). The source of microplastics in the atmospheric fallout could be judged based on the morphologic characterizations. Fibers might mainly derive from clothes and textiles (Browne et al. 2011), while films and fragments might originate from disposable plastic bags and thicker plastic products that might be recycled, respectively. Only two items of foams were found, which mainly originate from expanded polystyrene products.

Microplastics were found in all the atmospheric fallout samples from each site, indicating that the lower atmospheric environment (all the glass bottles in each site were almost 15 m above the ground) has been contaminated by microplastics. Dust emission from the land surface might be the main source of microplastics in the atmospheric fallout. Thus, dust emission and deposition between atmosphere, land surface, and aquatic environment were associated with the transportation of microplastics.

Composition

The chemical compositions of fibers and other suspected microplastics collected from atmospheric fallout in Dongguan were identified by μ-FTIR. Four kinds of polymers, i.e., polyethylene (PE), polypropylene (PP), polystyrene (PS), and cellulose, were identified (Fig. 2b–h and Fig. 3). Among the identified samples, the proportion of celluloses was the highest (73%), followed by PE (14%), PP (9%), and PS (4%). This is because of the fibers accounted for the vast majority of the suspected microplastics and were found in all sampling sites (Table 1). Notably, many fibers that were significantly overestimated as microplastics only by visual identification were non-plastics, and most of the identified fibers consisted of cellulose. In other words, most of them were natural fibers rather than synthetic fibers. In the industry, natural textile fibers even if made of cellulose, contain toxic dyes and additives (Remy et al. 2015). This could make them as dangerous as the synthetic ones.

Abundance

The abundance of non-fibrous microplastics and fibers in atmospheric fallout for 3 months (October to December) in each site was firstly counted according to the most commonly used criteria of visual observation (Table 1). Due to their large number and different lengths (Fig. 4), 20% of fibers were randomly selected to be detected. As shown in Fig. 5, 91.5% of them could be identified by μ-FTIR. 77.0% of the identified fibers were non-plastic and most of them consist of celluloses. In contrast, 84.6% of other shapes (i.e., films, fragments, and foams) of suspected samples were microplastics.

The concentrations of non-fibrous microplastics and fibers in the atmospheric fallout from October to November were 277 ± 32, 208 ± 3, and 198 ± 27 particles/m^2/day from sites S1 (Dongcheng), S2 (Guancheng), and S3 (Nancheng),

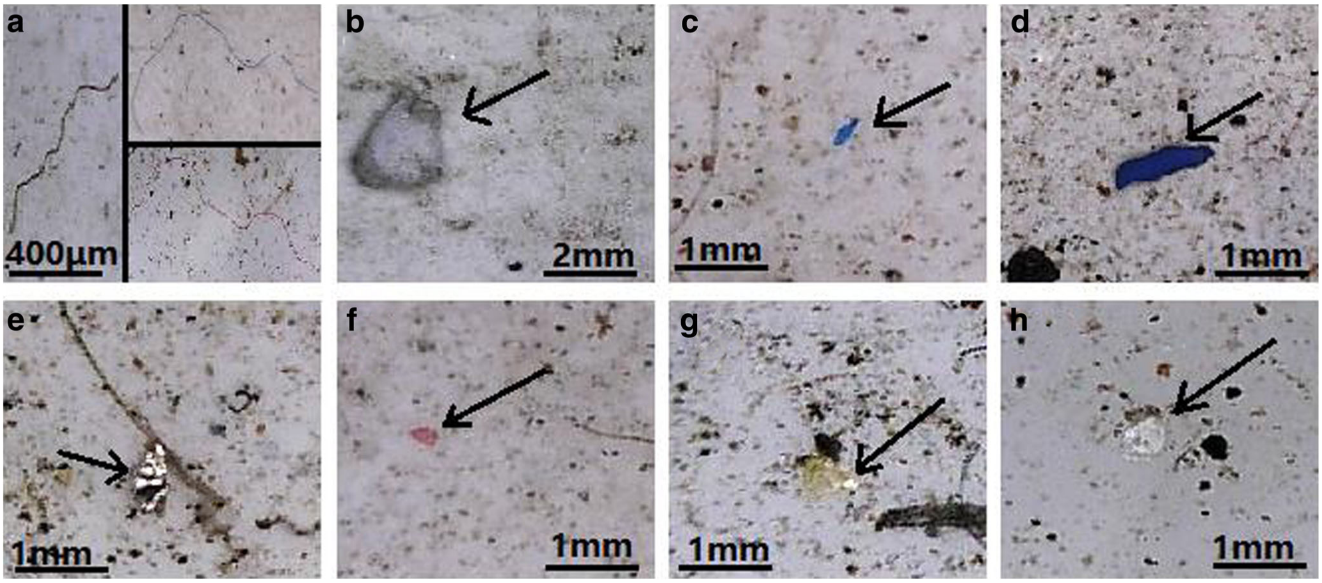

Fig. 2 Optical microscope images of selected polymers. **a** Colored fibers; **b** PS foam; **c**–**d** PP fragments; and **e**–**h** PE films

respectively. According to the rate of identified samples, the concentrations of microplastics were 43 ± 4, 33 ± 2, and 31 ± 8 particles/m^2/day in the atmospheric fallout from sites S1, S2, and S3, respectively. The average concentration of microplastics in the three sites was 36 ± 7 particles/m^2/day. Data on the presence of microplastics in the atmospheric fallout were lacking. But the abundance of textile fibers in Paris is 110 ± 96 particles/m^2/day (urban site) and 53 ± 38 particles/m^2/day (suburban site), and the synthetic fibers account for 29% were previously reported (Dris et al. 2016). In contrast, the abundance of microplastics in the atmospheric fallout from Dongguan city is much closer to the urban site

Fig. 3 FTIR spectra of identified polymers and the match degrees with the standard spectra

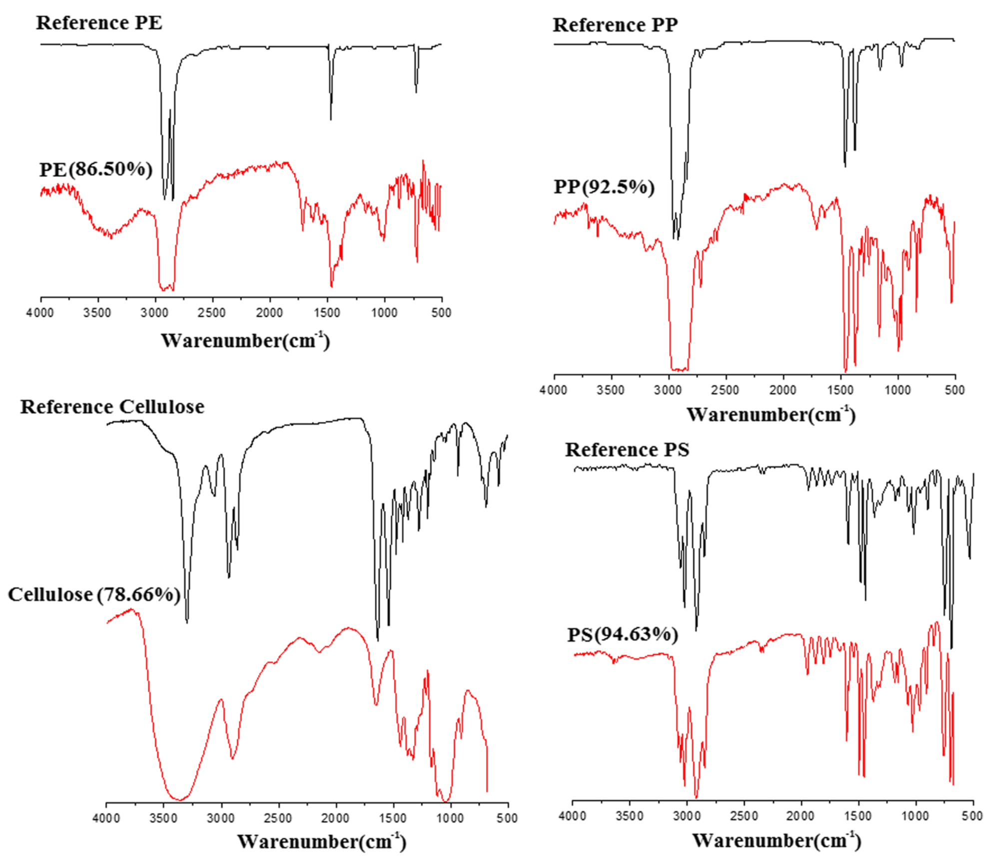

Table 1 Abundances of polymers collected from each site in Dongguan city

Sites	Period (2016)	Shape				Total[a]	Abundances[b] (particles/m^2/day)
		film	fragment	foam	fiber		
S1	Oct	5	8	–	159	172	313
	Nov	2	11	–	130	143	269
	Dec	3	11	–	123	137	250
S2	Oct	3	7	–	105	115	210
	Nov	4	8	1	96	109	205
	Dec	4	12	1	97	114	208
S3	Oct	3	6	–	95	104	190
	Nov	1	3	–	89	93	175
	Dec	7	10	–	108	125	228

[a] Concentrations of non-fibrous microplastics and fibers collected with samplers covering an area of 0.0177 m^2

[b] The abundances of non-fibrous microplastics and fibers were the monthly amounts and expressed in the number of particles/m^2 /day

but smaller than the suburban site in Paris. That is to say, the microplastic abundance of Dongguan city and Paris is on the same order of magnitude overall.

The highest and lowest concentrations of non-fibrous microplastics and fibers were found in site S1 (Laboratory middle school in the Dongcheng District) and site S3 (Dongguan Gym in the Nancheng District), respectively, while moderate concentrations, much closer to S3, were in site S2 (Waterworks in the Guancheng District). S1 was located in the school zone with dense population, while the density of population of S2 (waterworks) and S3 (gym) was relatively low. Thus, it seemed that the abundance of non-fibrous microplastics and fibers was closely related to the population and human activities in the sampling sites. Besides, taking the flux of atmospheric fallout (the total volume of collected samples in site S1, S2, and S3, respectively) into consideration, the numbers of non-fibrous microplastics and fibers were 248 items/L, 234 items/L, and 232items/L in S1, S2, and S3, respectively, which were consistent with the abundance of non-fibrous microplastics and fibers. It seemed that the flux of atmospheric fallout has a positive effect on the abundance of non-fibrous microplastics and fibers in each sampling site.

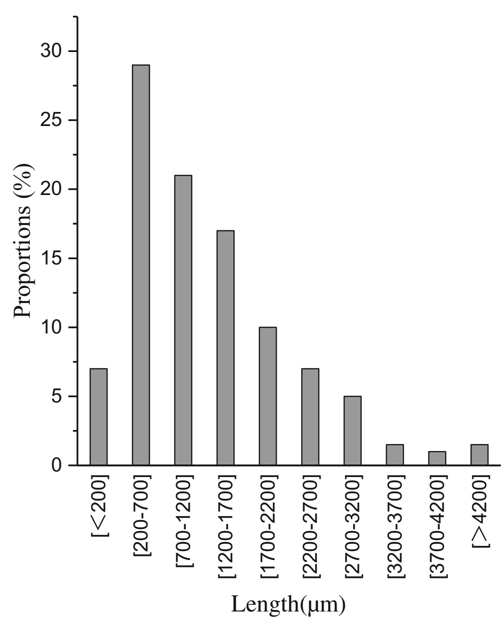

Fig. 4 Size distribution of microfibers collected from all three sampling sites

Surface textures

SEM images could clearly illustrate surface textures of synthetic fibers (Fig. 6a). Synthetic fibers exhibited relatively homogeneous and compact features. Besides, as shown in Fig. 6b–e, various degradation patterns, i.e., adhering particles, grooves, pits, fractures, and flakes, were found on microplastic surfaces, indicating that all the examined microplastics had experienced different levels of mechanical erosion and chemical weathering. Some microplastics (e.g.,

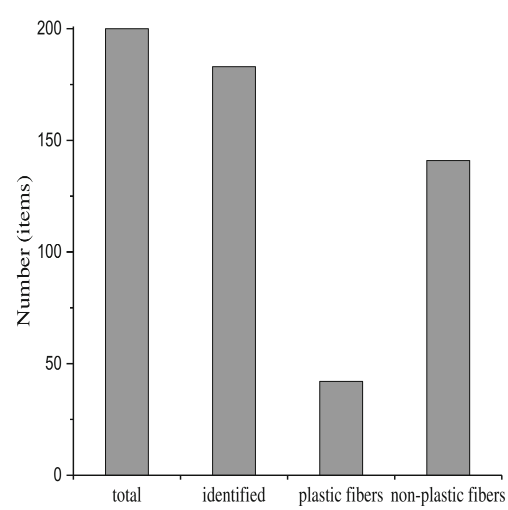

Fig. 5 Type of the selected fibers in the atmospheric fallout

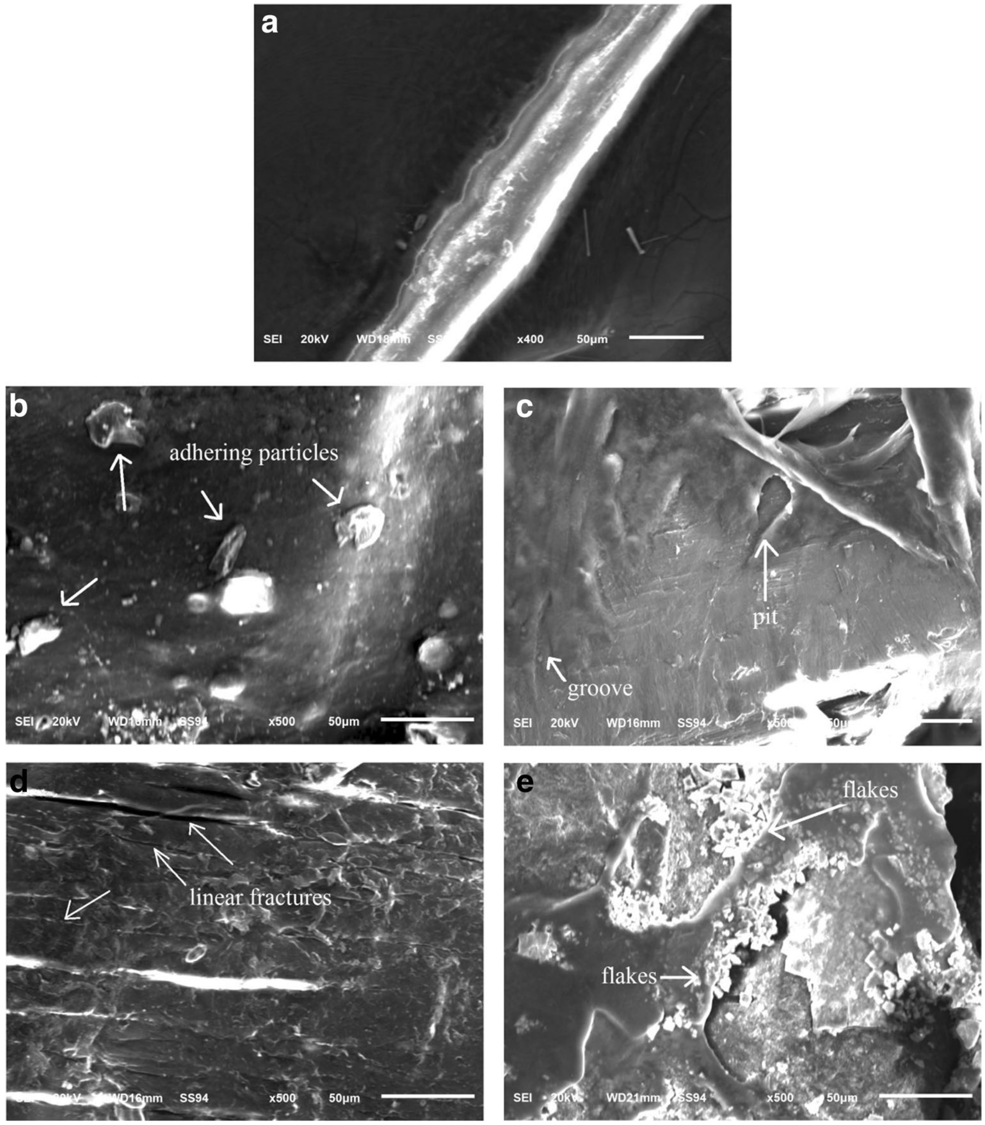

Fig. 6 SEM images of selected samples. **a** Synthetic fiber; **b** adhering particles on a film from site S2; **c** pit and groove on a film from site S2; **d** linear fractures on a fragment from site S3; and **e** flakes on a fragment from site S1

Fig. 6c) displayed more than one type of degradation patterns (i.e., pit and groove), which might be attributed to collision and friction caused by atmosphere dynamics. Other degradation patterns such as linear fractures might be attributed to the physical action of the wind. In addition to the mechanical abrasion, chemical weathering might also play a key role on the degradation of microplastics in the atmospheric environment. The chemical weathering of microplastics could be confirmed by FTIR spectra (Wang et al. 2017). As shown in Fig. 3, the FTIR spectra shows that new absorption peak appeared at about 1715 cm^{-1} in PE and PP, and another new absorption peak appeared at about 3300 cm^{-1} in PE, indicating that carbonyl (C = O) and hydroxyl (OH) groups were developed. This might be because they would be highly exposed to sunlight and have high oxygen availability, so will be chemically weathered. These degradation patterns of microplastics in atmospheric fallout were similar to those in marine beaches (Corcoran et al. 2009; Cooper and Corcoran 2010) and lakes (Zbyszewski and Corcoran 2011; Zbyszewski et al. 2014; Zhang et al. 2016). Such similar patterns indicate that the source of microplastics in the aquatic environment might be derived from atmospheric fallout.

Conclusion

Though the density of air is lower than those of all types of microplastic, the question that whether microplastics could suspend in the air remains to be determined due to air dynamics (Peng et al. 2017). It is noteworthy that, however, microplastics in the atmospheric fallout from three sites of the air monitoring system in Dongguan Environmental Monitoring Central Station were found in this study. Microplastics of three different polymers, i.e., PE, PP, and PS, were identified. Microplastics could be categorized into four types, i.e., foam, fragment, film, and fiber, and fiber was the dominant shape. SEM images illustrated that adhering particles, grooves, pits, fractures, and flakes were the common patterns of degradation. The concentrations of non-fibrous microplastics and fibers ranged from 175 to 313 particles/m^2/day in the atmospheric fallout. According to the rate of identified samples, the concentrations of microplastics ranged from 31 ± 8 to 43 ± 4 particles/m^2/day. Thus, dust emission and deposition between atmosphere, land surface, and aquatic environment were associated with the transportation of microplastics. In addition, more attention must be paid on the contamination of non-fibrous microplastics and fibers in the lower atmospheric environment for potential inhalation by human beings, particularly by young children (Peng et al. 2017).

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