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Influence of Tourmaline on Negative Air Ion Emitting Property of Poly(ethylene terephthalate)

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Poly(ethylene terephthalate) (PET) fibers containing 2 wt% tourmaline powder were found to emit an average 5100 particles/cc negative air ions under frictional conditions, much higher than that of pure poly(ethylene terephthalate) fibers which emitted an average 200 particles/cc negative air ions, but the emitted negative air ions were reduced to 4400 particles/cc when poly(ethylene terephthalate) fibers contained 4 wt% tourmaline powder. In order to understand the influence of tourmaline powder on the negative air ion emitting property of the poly(ethylene terephthalate) fibers, scanning electron microscopy (SEM) morphology, energy dispersive X-rays (EDX) and wide angle X-ray diffraction (WAXD) analysis of the PET/tourmaline fiber specimens were performed. Possible reasons are proposed to account for the interesting negative air ion emitting property of the PET/tourmaline fiber specimens. Aggregates of tourmaline powder occurred in the PET matrix, which caused a reduction of the breaking tenacity of the PET/tourmaline fibers.

Keywords tourmaline, poly(ethylene terephthalate), negative air ion, scanning electron microscopy, energy dispersive X-ray, wide angle X-ray diffraction

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Introduction

Negative ions present in air are generally recognized as being capable of exhibiting an invigorating effect on living bodies by normalizing the autonomic or motorial nervous system. Biological functions of the person under the influence of negative ions is improved, such as sleep-stimulation, good mood, activation of body cells, acceleration of metabolism, blood circulation and fatigue recovery and so on (1–4). For convenience, these negative ions present in air will be referred to as negative air ions in the following discussion. Presumably, they can be present as varying types of negative air ions, such as $O_2^-(H_2O)_n$, $OH^-(H_2O)_n$ or $CO_4^-(H_2O)_2$ (1–5), when enough moisture is present in the ambient environment. Thus, investigation of methods of emitting negative air ions has drawn much attention for years.

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Natural tourmaline minerals can generate negative air ions spontaneously and permanently. A tourmaline crystal maintains a pair of electrodes with no supply of external electric energy, which can be recognized as permanent electrodes that can generate negative air ions (6, 7). To date, tourmaline has been found to improve the quality of water (8–10), and has been used in cosmetic products (11), tooth polishing agents (12), paints (13), environment decontamination (14–16), and to produce synthetic textiles with functions of promoting blood circulation and accelerating metabolism in living bodies (17–21).

In this study, tourmaline containing poly(ethylene terephthalate) (PET) fibers were produced, and the concentrations of negative air ions emitted from tourmaline containing poly(ethylene terephthalate) (PET) fiber specimens under frictional conditions were investigated. The main objective of this study was to investigate the influence of tourmaline content on the concentrations of negative air ions emitted from tourmaline containing poly(ethylene terephthalate) (PET) fiber specimens. Possible underlying mechanisms accounting for the interesting negative air ion properties observed in this study are proposed.

Experimental

Materials and Sample Preparation

Poly(ethylene terephthalate) (PET) was obtained from Jinxing Fibers Corporation, (Fujian, China), and tourmaline powder from Dazhao Industry and Trade, Ltd. Co., (Shanghai, China). Titanate coupling agent NDZ-130 was obtained from the Nanjing Shuguang Chemical Plant.

Before tourmaline powder was mixed in the PET, it was surface-modified with 5 wt% titanate coupling agent NDZ-130 so as to prevent flocculation of the tourmaline powder in the PET matrix.

PET master batch resins with tourmaline powder were prepared by feeding the PET and modified tourmaline powder into a SHL-35 twin-screw extruder at a weight ratio of 80:20. The extruded master batch resins with tourmaline powder were then quenched in cold water and cut into pellet form. The PET fibers with tourmaline powder were prepared by melt spinning and drawing of the master batch resins mixed with varying amounts of pure PET resin in a MST C-400 melt spinning machine (made in Japan). Table 1 summarizes the compositions of the PET/tourmaline fibers and their spinning temperatures used in this study.

Table 1
Compositions and production temperature of the PET/tourmaline fibers

Fiber specimens	Modified tourmaline (wt%)	PET (wt%)	Spinning temperature
PET_0	0	100	285°C
PET_2	2.0	98.0	276°C
PET_4	4.0	96.0	273°C

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Negative Air Ion Analysis

The concentration of negative air ions emitted from the PET/tourmaline fiber specimens were determined using an Andes air ion detector model IC-1000 (made in Japan) under frictional conditions by rubbing the PET/tourmaline fibers with themselves manually.

Morphology and Surface Composition Analysis of PET/Tourmaline Fiber Specimens

In order to understand the distribution of tourmaline particles in the PET fiber specimens, the tourmaline powder and PET/tourmaline fiber specimens prepared in the previous section were observed using a JSM-5600LV scanning electronic microscope (SEM) (made in Japan). The compositions of particles on the surface of the fiber specimens were determined with a Siemens D5000S energy dispersive X-ray system (EDX).

Wide Angle X-Ray Diffraction

The wide angle X-ray diffraction (WAXD) properties of the PET/tourmaline fiber specimens were determined using a Rigaku D/max-B diffractometer (made in Japan).

Mechanical Properties Determination

Mechanical properties including breaking elongation and breaking tenacity were determined in a WPW-20 electronic multi-functional fiber tester made in the Hualong instrument plant in Shanghai.

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Results and Discussion

Morphology and Surface Composition Analysis

Typical SEM micrographs of the surface of PET/tourmaline fiber specimens are summarized in Figure 1 (c and e). It is interesting to note that many of the tourmaline powder have diameters ranging from about 0.5 μm to 3 μm when dispersed in the PET matrix. As shown in Figure 1(a), the average diameter of the original tourmaline powder was about 0.3 μm with relatively small size distribution. Apparently, some of the tourmaline powder significantly coagulated during the preparation processes of the PET/tourmaline fiber specimens. For example, the largest size of the aggregated tourmaline powder increased from about 1 to 3 μm as the tourmaline contents in PET/tourmaline fiber specimens increased from 2 to 4 wt%, respectively (Figure 1 (c and e)). As show on Figure 1(c), the average particle size of tourmaline powder increased slightly to 0.5 μm in the PET_2 specimen. However, the average particle size increased significantly to about 1 μm for the 4 wt% tourmaline content. These results clearly suggested that, with tourmaline content of 2 wt%, the surface modified tourmaline powder could be relatively well dispersed in PET matrix by melt blending, but that, significant aggregation of the tourmaline powder occurred as their content was increased to 4 wt% even though the tourmaline powder was treated with a titanate coupling agent. One might expect that, if there was more tourmaline powder in the PET matrix, more negative air ions could be emitted by the PET/tourmaline fibers, but significantly aggregated tourmaline particles at higher loadings significantly reduced their effective surface areas for emitting negative air ions.

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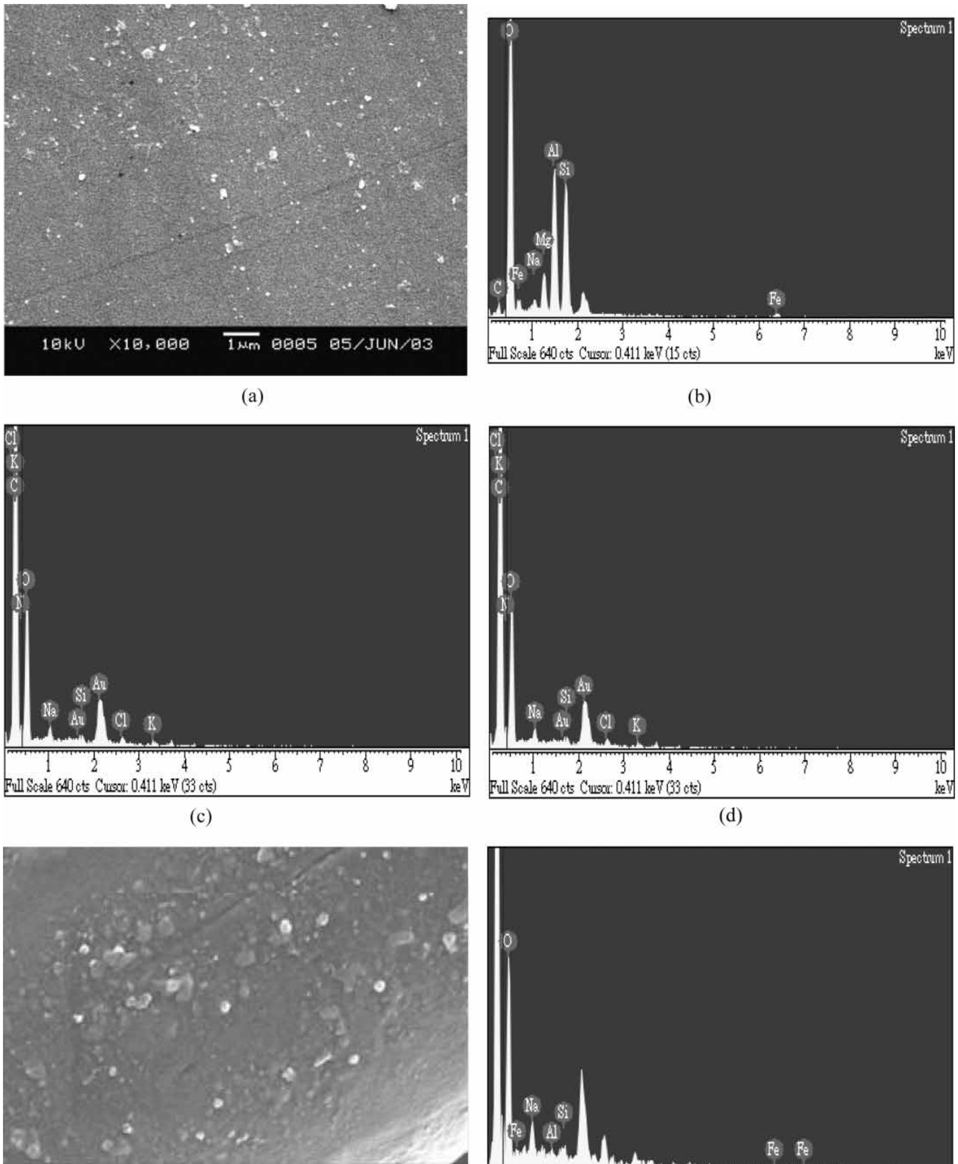

(a) (b)

(c) (d)

(e) (f)

Figure 1. (a) SEM micrographs of the tourmaline powder, (b) EDX spectrum of the tourmaline powder (a), (c) SEM micrographs of the surface of PET_2, (d) EDX spectrum of a tourmaline particle on the surface of PET_2, (e) SEM micrographs of the surface of PET_4, (f) EDX spectrum of a tourmaline particle on the surface of PET_4.

Figure 1 (d and f) summarize the EDX analysis of the compositions of particles on the surface of the PET/tourmaline fiber specimens. Compared with Figure 1(b) of the original tourmaline particles, the particles of Figure 1 (d and f) presented almost the same compositions. This demonstrates that the particles on the surface of specimen PET_2 and PET_4

were tourmaline powder. It is thus expected that it was the tourmaline powder that endowed the PET/tourmaline fibers with negative air ion emitting property.

Negative Air Ion Releasing Properties

Table 2 summarizes the average concentration of negative air ions (C_{ion-}) emitted from PET/tourmaline fiber specimens tested under frictional conditions. Only about 200 particles/cc of negative air ions were emitted from the pure PET fiber specimens. After blending tourmaline powder in the PET fibers, the C_{ion-} values of the PET/tourmaline fiber specimens increased significantly. The average C_{ion-} value of PET/tourmaline fiber specimen reached 5100 particles/cc as the tourmaline content was 2 wt%, but reduced significantly to 4400 particles/cc when the tourmaline was 4 wt%. Presumably, this significantly reduced C_{ion-} can be attributed to the aggregation of the tourmaline powder at high tourmaline loadings, since the effective surface areas for emitting negative air ions of tourmaline powder was reduced significantly as the tourmaline powder was aggregated. It is believed that the negative air ion emitting property of the PET/tourmaline fibers can be greatly improved if we can solve the problem of coagulation of tourmaline powder in the PET matrix.

The concentration of C_{ion-} emitted from PET/tourmaline fiber specimens was tested under frictional conditions, because tourmaline is a piezoelectric mineral, and the efficiency of releasing negative air ions of the tourmaline crystals were expected to improve with an ambient pressure change.

Wide Angle X-ray Diffraction

Typical wide angle X-ray diffraction (WAXD) patterns of the PET/tourmaline fiber specimens and pure PET fibers are shown in Figure 2(a). The characteristics of the WAXD patterns of PET_0 and PET_2 are similar, but different from that of PET_4, which indicated that the tourmaline fine particles of 2 wt% content had a smaller effect on the crystallization behavior of the PET fibers than that of 4 wt% content.

We calculated the crystallinity of the three specimens with PeakFit software. Figure 2(b) is the wide angle X-ray diffraction (WAXD) patterns of the PET_2, and three resolved crystalline peak curves and one amorphous halo. The crystallinity of the PET_2 was calculated as follows:

$$X_C = S_C/(S_C + S_\delta) \tag{1}$$

$$S_C = S_\alpha + S_\beta + S_\gamma \tag{2}$$

Table 2
Average concentration of negative air ions (C_{ion-}) emitted from the PET/tourmaline fiber specimens

Fiber specimens	Average concentration of negative air ions (particles/cc)
PET_0	200
PET_2	5100
PET_4	4400

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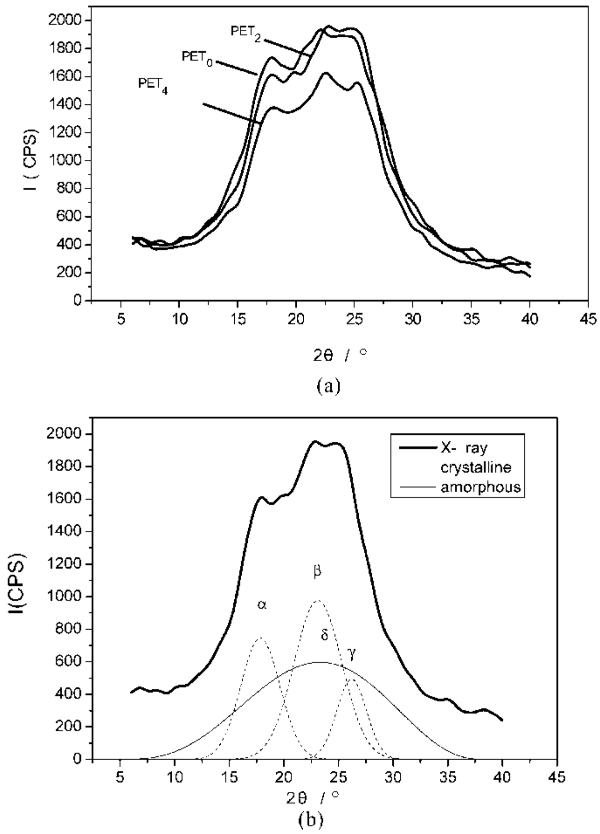

Figure 2. (a) WAXD patterns of the PET/tourmaline fiber and pure PET fiber specimens, (b) WAXD patterns of the PET_2 and its parted crystalline curves and amorphous halo.

where X_C is the crystallinity of the PET_2, S_C is the total integral area of the three crystalline peak areas curve zone, and S_δ is the integral area of the amorphous halo. We calculated that S_α, S_β, S_γ, and S_δ were 98.50, 157.88, 49.57, and 265.83, respectively, by which X_C was calculated as 53.5%. The crystallinities of PET_0 and PET_4 were also calculated in the same way, being 41.8% and 68.7%, respectively; thus the crystallizatimity of the PET fibers containing tourmaline was increased. With more tourmaline powder in the PET matrix, the crystallization was increased more. The reason is attributed to the tourmaline powder in the PET matrix during the spinning, which acted as crystal nuclei during the crystallization of the PET matrix. The crystal nuclei accelerated the crystallization of the PET matrix.

Mechanical Properties

The mechanical properties, including breaking elongation and breaking tenacity, of the PET/tourmaline fiber specimens are listed in Table 3. Compared with pure PET fibers, the breaking tenacity of the PET/tourmaline fibers was reduced. With more tourmaline powder in the PET matrix, the breaking tenacity of the PET/tourmaline fibers was lower.

Table 3
Mechanical properties of the PET/tourmaline fiber specimens

Fiber specimens	Breaking elongation (%)	Breaking tenacity (cN/dtex)
PET_0	20.3	3.64
PET_2	14.4	2.71
PET_4	16.4	2.31

One might expect the PET fibers with higher crystallization to have better mechanical properties; they had poorer mechanical properties. We attribute this to the large aggregates of the tourmaline powder, which were not well bonded to the matrix. With more tourmaline powder, there were more tourmaline aggregates in the PET matrix, as shown in Figure 1 (c and e), which caused the reduction of the breaking tenacity of the fibers.

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Conclusions

The average C_{ion-} value of the pure PET fiber specimens tested under frictional condition was only 200 particles/cc. After blending with tourmaline powder, the efficiency of emitting negative air ions of PET/tourmaline fiber specimens improved significantly to average 5100 particles/cc when the tourmaline content was 2 wt%.

The significantly reduced average C_{ion-} value of 4400 particles/cc of PET/tourmaline fiber specimens with tourmaline content of 4 wt% was attributed to aggregation of tourmaline powder at high tourmaline loading.

The tourmaline powder caused higher crystallization of the PET matrix. The aggregates of the tourmaline powder in the PET matrix reduced the breaking tenacity of the PET/tourmaline fibers.

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