Research Article

Wei Cao, Qiuying Li*, and Chifei Wu*

The HDPE composites reinforced with waste hybrid PET/cotton fibers modified with the synthesized modifier

https://doi.org/10.1515/epoly-2022-0008
received September 02, 2021; accepted November 03, 2021

Abstract: Large amounts of textile waste are generated every year and disposed of through landfill or incineration, leading to numerous environmental and social issues. In this study, waste hybrid polyethylene terephthalate (PET)/cotton fibers were used directly to reinforce high density polyethylene (HDPE) to prepare composites. In order to give full play to the fiber's reinforcing characteristics, the PET/cotton fibers were further modified with the modifier using a novel synthesized tetraethyl orthosilicate/3-aminopropyl triethoxysilane (KH550)/polyethylene (PE)-g-MAH (MPE) hybrid (TMPE). Fourier transform infrared and scanning electron microscopy (SEM) confirmed that the TMPE was successfully coated on the surface of fibers. Furthermore, compared with the original and the MPE-modified fibers, the thermal stability of TMPE-modified fibers was significantly increased. SEM and mechanical test indicated that the compatibility of the modified fibers with HDPE had been significantly improved, which led to the improvement of mechanical properties. Compared with the original and MPE-modified fibers-reinforced HDPE composites, the bending strength, bending modulus, and impact strength of TMPE-modified fiber-reinforced HDPE composites were improved obviously by 31.7%, 25.7%, and 89.1%, respectively.

Keywords: PET/cotton fibers, modification, compatibility, thermal stability, HDPE

1 Introduction

Due to the increase of world population, the rapid change of fashion cycle, and the improvement of people's quality of life, waste fabrics have been increasing steadily in the past few decades. If the fabrics are in the pure form, e.g., cotton or PET, different recycling or reuse techniques can be developed on a large scale. However, waste textiles are generally hybrid PET/cotton fabrics (a general term for blended fabrics of PET and cotton). In most countries, people choose to bury waste textiles in land (landfill) in order to dispose them (1), which not only is a waste of resources, but also pollutes the environment. Compared with landfill, recycling and reuse of PET/cotton fabrics are obviously much preferable (2).

In previous studies, the recycling and reuse of hybrid PET/cotton fabrics were mainly to separate the waste PET/cotton fabrics into different products. This may be done by depolymerizing or dissolving one component while maintaining the other. For example, to maintain the PET, people can degrade the cotton either with acid or microbes (3–5). Then the maintained PET can be melted and woven into new products in textile manufactures. It is also possible to maintain the cotton and depolymerize or dissolve the PET (6,7). However, cotton fibers with cellulose as the main component are easy to be damaged to a certain extent after mechanical or chemical treatment. Therefore, recycled cotton fibers can only be used for low-value textiles, such as carpets, fillers, and nonwoven fabrics (8,9). In addition, the use of solvents and the generation of hazardous wastes in the process of separation inevitably bring new environmental problems, and the fibers being separated may have incomplete separation or mechanical property deterioration caused by damages. Therefore, their reuse value is relatively low.
mical bonding and mechanical interlocking between the necessary that the thermal stability of the hybrid PET/cotton have been carbonized. So, it is necessary to improve the matrix determines the key to the stress transfer efficiency of high-performance fiber-reinforced materials. Therefore, it is necessary that the fibers be modified to improve the chemical bonding and mechanical interlocking between the fiber and the polymer matrix (11–13). So, the other problem is how to choose the suitable modification method to modify the hybrid PET/cotton fibers. Most of previous studies were based on surface chemical etching (alkali treatment), graft modification (14), plasma modification (15), and coating method (16). These studies have shown that alkali treatment can easily control the reaction time and temperature. In addition, it is possible to design and predict the decrease in fiber strength and weight loss. Therefore, alkali treatment is usually the basic treatment and grafting and coating treatment further functional treatment (17,18).

In our previous study (19), through the sol–gel method, SiO₂ was connected to the polypropylene-g-MAH molecular chains through a silane coupling agent, which was used to coat PET fibers to form an inorganic–organic film on the surface of the glass fibers. The results have proved that the modification effect is obvious, and the properties of PP composites have been significantly improved. So the same modification method was used to modify the surface of hybrid PET/cotton fibers, for the purpose of improving the thermal stability of the fibers and the compatibility of the fibers with high density polyethylene (HDPE), so as to further improve the performance of the composite material and provide an optional method for reusing the hybrid PET/cotton fibers.

2 Experimental

2.1 Materials

The 10-count PET/cotton yarn (provided by Weifang Xinhui Textile Co., Ltd) was made of 65% polyester and 35% cotton fiber twisted. The matrix material was HDPE with a density of 0.96 g cm⁻³, and melt flow rate = 7.3 g 10 min⁻¹ (2.16 kg, 230°C, PetroChina Company Limited). Maleic anhydride grafted polyethylene (PE-g-MAH, MPE) was provided by Ningbo Nengzhiguang New Material Technology Co., Ltd., with a density of 0.96 g cm⁻³ and a free maleic anhydride content of less than 1.0%. Other materials were of analytical grade and all materials were used according to the received dose.

2.2 Synthesis of modifier

The hybrid modifier was synthesized by referring to the process of previous work (19): PE-g-MAH powder was added to a boiling xylene solution until the powder dissolved (solution A). Tetraethyl orthosilicate (TEOS), P-toluene sulfonic acid (PTSA), and xylene were mixed at room temperature according to the mass ratio of 1:0.01:20, and the mixture was continuously stirred (solution B). KH550 was mixed with xylene at room temperature in the mass ratio of 0.5:20, and the mixture was continuously stirred (solution C). Then, solution A, B, and C were mixed at 130°C for 1 h. The fiber modifier named TMPE was accomplished. It should be noted that the entire process of synthesizing the modifier should be in an anhydrous environment to prevent the hydrolysis reaction of TEOS from precipitation of SiO₂, destroying the stability of the colloid.

2.3 Surface treatment of PET/cotton fibers

The PET/cotton fibers were soaked in a mixed solution of acetone and water (volume ratio 1:1) for 2 h, then washed with deionized water for 3–4 times, and finally dried at 85°C. Then the dried fibers were soaked in NaOH (0.01 mol L⁻¹) solution at 80°C for 1 h and dried again. Thereafter, they were dried and modified by MPE and TMPE solution by impregnation methods, respectively. Finally, the modified fibers were placed at room temperature for 3 days. When the modifier was completely hydrolyzed, SiO₂/MPE composite powders were
formed on the surface of the PET/cotton fibers. The reaction mechanism was shown in Eqs. (1)–(6):

(a) The hydrolysis reaction of TEOS:

\[
\begin{align*}
\text{C}_2\text{H}_5\text{OH} + \text{SiO}_2\text{C}_2\text{H}_5 & \rightarrow \text{HO-Si-OH} + 4\text{C}_2\text{H}_5\text{OH} \\
\end{align*}
\]

(b) The hydrolysis reaction of KH550:

\[
\begin{align*}
\text{C}_3\text{H}_6\text{H}_2\text{N} + \text{SiO}_2\text{C}_2\text{H}_5 & \rightarrow \text{HO-Si-OH} + \text{C}_3\text{H}_6\text{H}_2\text{N} + 3\text{C}_2\text{H}_5\text{OH} \\
\end{align*}
\]

(c) The reaction of TEOS and KH550 hydrolyzate:

\[
\begin{align*}
\text{HO-Si-OH} + \text{C}_3\text{H}_6\text{H}_2\text{N} & \rightarrow \text{Si-OH} + \text{C}_3\text{H}_6\text{H}_2\text{N} + 6\text{C}_2\text{H}_5\text{OH} \\
\end{align*}
\]

(d) The generation of silica groups with amine groups:

\[
\begin{align*}
\text{HO-Si-OH} + \text{C}_3\text{H}_6\text{H}_2\text{N} & \rightarrow \text{Si-OH} + \text{C}_3\text{H}_6\text{H}_2\text{N} + x\text{H}_2\text{O} \\
\end{align*}
\]

(e) Interaction between MPE and amine groups

\[
\begin{align*}
\text{H}_2\text{N-C}_3\text{H}_6 & + \text{R'-COOH} \rightarrow \text{H}_2\text{NC}_3\text{H}_6 \text{R'-COOH} \\
\end{align*}
\]

(f) Synthesis of TMPE on the fiber surface:

\[
\begin{align*}
\text{R'-COOH} + \text{C}_2\text{H}_5\text{OH} & \rightarrow \text{R'-COOH} + \text{C}_2\text{H}_5\text{OH} + \text{H}_2\text{O} \\
\end{align*}
\]

2.4 Preparation of composites

The HDPE and fibers were mixed for 8 min in the mass ratio of 70:30 in the HAAKE at 180°C under the rotor speed of 60 rad·s⁻¹. And then the mixture was pressed into 4 mm thick plate at 180°C for 6 min under the pressure of 7.5 MPa. According to the modification of PET/cotton fibers, these composites were divided into HDPE, HDPE reinforced with original fibers, HDPE reinforced with MPE-modified fibers, and HDPE reinforced with TMPE-modified fibers.

2.5 Characterizations

2.5.1 Scanning electron microscope

Scanning electron microscopy (SEM, S-4800N, Hitachi, Tokyo, Japan) was used to examine the morphology of the modified fibers and the impact cross-section of the PET/cotton fibers/HDPE composites. Samples were treated with spray gold craft before observation.

2.5.2 Fourier transform infrared spectroscopy

Fourier transform infrared (FTIR, Nicolet Magna-IR550, Thermo Electron, New York, USA) was used to characterize the modifier powders. The samples were loaded onto potassium bromide tablets.

2.5.3 Thermogravimetric analysis

The thermal stability of the modified fibers was tested by thermogravimetric analysis (TGA, Pyris6, Perkin-Elmer, Waltham, MA, USA). The samples were heated from ambient temperature to 800°C at a heating rate of 10°C·min⁻¹ under the nitrogen atmosphere with a flow rate of 50 mL·min⁻¹.
2.5.4 Color difference analysis

Color difference meter (SC-10, 3nh, Shenzhen, China) was used to analyze the color of the prepared PET/cotton fibers/HDPE composite material. The colorimeter uses the L, a, b color system, and the color change can be represented by Eq. 7:

\[ \Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \]  

(7)

where \( \Delta E \): degree of discoloration; \( L \): from 0 to 100, +ΔL means white, −ΔL means black; \( a \): from −150 to +150, +Δa means red, −Δa means green; \( b \): from −150 to +150, +Δb means yellow, −Δb means blue.

2.5.5 Mechanical properties

The breaking force of a single yarn was tested with a universal tensile machine (XQ-1, Shanghai) in accordance with GB/T 14337-2008. The bending properties of the PET/cotton fibers/HDPE composites were tested by a universal tensile machine (CMT-20KN, Shenzhen). The test sample was prepared according to GB/T 9341-2008. The impact strength of the composites was measured by the cantilever beam impact tester (CEAST-9050, Italy), which was prepared according to GB/T 1834-2008.

3 Results and discussion

3.1 FTIR of modifier

The FTIR spectra of MPE and TMPE are shown in Figure 1. Absorption peaks at 3,421, 2,740, and 1,100 cm\(^{-1}\) are absent in MPE, but present in TMPE. Among them, 3,421 cm\(^{-1}\) is the N–H stretching vibration belonging to the amide group, 2,740 cm\(^{-1}\) is the stretching vibration belonging to the amine salt, and 1,100 cm\(^{-1}\) is speculated to be the antisymmetric stretching vibration peak of Si–O–Si. It can be seen from the figure that TMPE has only one peak between 3,300 and 3,500 cm\(^{-1}\), and the number of peaks in this wave number corresponds to the number of N–H bonds, so there is an imine group peak at 3,411 cm\(^{-1}\). The characteristic peak of the amine salt at 2,740 cm\(^{-1}\) indicates that part of the amine group reacts with PTSA. Based on the structures of KH550, TEOS, and MPE, it can be concluded that the amine group in KH550 reacts with the anhydride in MPE to form an imino group (amide) close to the carbonyl group, and the alkoxy group of KH550 is hydrolyzed. Then, it reacts with TEOS hydrolyzed hydroxyl group to form a strong silicon–oxygen bond to form an organic–inorganic hybrid layer.

3.2 Modified PET/cotton fibers

3.2.1 Dimensional changes of PET/cotton fibers in microstructure

Figure 2 shows the SEM figures of hybrid PET/cotton fibers. PET fibers and cotton fibers are randomly...
distributed among the hybrid fibers (Figure 2a). PET fiber is regular and has a smooth surface, while cotton fiber has wrinkled and irregular surface due to its bending in the natural growth process (Figure 2b and c).

Figure 3 shows the effects of modifiers on the surface morphology of PET fibers and cotton fibers, respectively. Apparently, the surface of the fibers is not uniformly packed with MPE particles (Figure 3a and b). However, compared with the MPE-modified fibers, the surface of TMPE-modified fibers is uniformly modified with a coating (Figure 3c and d). This not only protects the fibers to some extent, but also increases the contact area between the fibers and the matrix. By comparing the morphology characteristics of MPE-modified fiber and TMPE-modified fiber, it can be concluded that the modified coatings on the surface of the fibers are composed of silicon-oxygen bonds and MPE, and SiO$_2$ with amino groups inhibits the agglomeration of MPE. In addition, SiO$_2$ provides a nucleating agent for MPE and disperses MPE, thereby increasing the probability of contact between the modifier and the terminal hydroxyl groups on the fiber surface, which make the reaction more completely and the modified coating more closely combined.

3.2.2 Thermal stability analysis of PET/cotton fibers

The TGA curves of original fibers, MPE-modified fibers, and TMPE-modified fibers are shown in Figure 4. Figure 4 shows that there appear two stages of weight loss and decomposition. The first stage is the decomposition of cotton fibers, and the second stage is the decomposition of PET fibers. Table 1 shows the temperature of every stage of weight loss and decomposition. It can be clearly seen from Table 1 that compared with the original fibers and the MPE-modified fibers, the decomposition temperatures of TMPE-modified cotton fibers and PET fibers are both significantly increased by 30°C and 33°C, respectively. This shows that TEOS and KH550 formed a dense inorganic layer on the surface of fibers by the amine-based SiO$_2$ layer formed by the mutual reaction between

![Figure 3: SEM images of (a and b) MPE-modified fibers and (c and d) TMPE-modified fibers.](image)

![Figure 4: TGA curves of (a) original fibers, (b) MPE-modified fibers, and (c) TMPE-modified fibers.](image)
their hydrolyzed products, thereby improving the thermal stability of PET/cotton fibers. In addition, the thermal conductivity of SiO₂ is much higher than that of the fibers. After heat enters the modified fibers, it will first be transferred between SiO₂, thus temporarily protecting other components.

### 3.2.3 Mechanical test of PET/cotton yarn

According to Figure 5, the breaking force of TMPE-modified fibers is much higher than that of original fibers and MPE-modified fibers. After the fiber is alkali-treated, many terminal hydroxyl groups will be produced on the surface. These active groups can react with MPE to connect MPE and fiber together. The experimental raw materials are polyester and cotton fibers twisted together. The distance between them is very close, and these fibers are connected to form a whole through MPE, thereby effectively improving the strength of the yarn. Due to the addition of TEOS in TMPE modifier, the fiber’s surface was coated with a modified coating, and the agglomeration of MPE was inhibited and the dispersion was more uniform. This covering structure can not only repair the defects on the fiber surface, but also increase the stress transmission between the fibers to further enhance the strength of the TMPE-modified yarn.

### 3.3 Analysis of PET/cotton fibers/HDPE composite material

#### 3.3.1 Microstructure of composite material section

Figure 6 shows the microscopic morphology of the impact section of the HDPE composite reinforced with fibers. The original fibers apparently separate from the HDPE matrix (Figure 6a). Compared with the original fibers-filled HDPE, the gap between the fibers and matrix in the MPE-modified fibers-filled HDPE got smaller (Figure 6b) for improving the compatibility between the MPE-modified fibers and the matrix. In Figure 6c, the fibers and the HDPE matrix are tightly combined into a whole, which proves that TMPE modifiers are advantageous to improve the compatibility of the fibers and the HDPE matrix.

#### 3.3.2 Analysis of color difference of composite materials

Figure 7 shows the specimen surface photos of HDPE filled with the original fibers, MPE-modified fibers, and

![Figure 5: Breaking force of PET/cotton yarn.](image)

**Table 1:** The temperatures of every stage of weight loss and decomposition

| Sample            | The temperature of the first stage (°C) | The temperature of the second stage (°C) |
|-------------------|----------------------------------------|-----------------------------------------|
| Original fibers   | 320–360                                | 370–450                                 |
| MPE-modified fibers | 325–365                                | 375–455                                 |
| TMPE-modified fibers | 350–390                                | 403–483                                 |

![Figure 6: SEM images of impact cross-sections of (a) original fibers/HDPE, (b) MPE-modified fibers/HDPE, and (c) TMPE-modified fibers/HDPE.](image)
TMPE-modified fibers. In the process of composite material processing, cotton fibers are partially carbonized, so the color of the composite material is brown (Figure 7a). However, the surface of the composites filled with modified fibers changes progressively to chalky white but in a different whitening rate (Figure 7b and c). In order to further understand the surface whitening, the color difference meter was used to observe the whitening area, as shown in Table 2. As can be seen from the Table 2, the value with the biggest change of the three samples is $L$ value, and $L$ represents the change of black and white color. Table 2 shows that the color of the material filled with the TMPE-modified fibers is the lightest, which shows that TMPE has a significant improvement in the thermal stability of the fibers. The compatibility of the MPE-modified fibers with HDPE has been enhanced to a certain extent, so that the matrix can better cover the fibers during processing, thereby reducing the contact between fibers and air, which inhibit the carbonization of fibers. For the TMPE-modified fibers, the compatibility of the fibers and the matrix was increased significantly for the uniform distribution of the denser modifier, resulting in the filled composite materials having the lightest color.

### 3.3.3 Mechanical analysis of composite materials

Figure 8 shows the bending strength and modulus of HDPE filled with fibers, respectively. Compared with HDPE, the bending strength and modulus of composites filled with PET/cotton fibers improved significantly. Moreover, the performance of the composites filled with TMPE-modified fibers is the best among all the samples. Compared to the composites filled with the original fibers, the bending strength and modulus of composites filled with TMPE-modified fibers increased by 4.89 and 129.03 MPa, respectively. Figure 9 shows the impact performance of the composite material. It can be seen from the figure that the impact strength of unmodified fiber-reinforced HDPE is 14.78 kJ·m$^{-2}$, and the impact strength of MPE and TMPE-modified fiber-reinforced HDPE are 23.64 and 27.95 kJ·m$^{-2}$, an increase of 60.0% and 89.1%, respectively.

### Table 2: Data of composites measured by the color difference meter

| Sample                     | $L$  | $a$  | $b$  | $\Delta L$ | $\Delta a$ | $\Delta b$ |
|----------------------------|------|------|------|------------|------------|------------|
| Original fibers/HDPE       | 47.61| 6.22 | 11.29| 0          | 0          | 0          |
| MPE-modified fibers/HDPE   | 54.14| 4.92 | 11.87| 6.53       | -1.3       | 0.58       |
| TMPE-modified fibers/HDPE  | 55.97| 5.21 | 12.65| 8.36       | -1.01      | 1.36       |

![Figure 7](image1.png) **Figure 7:** Composite specimen surface photos of (a) original fibers/HDPE, (b) MPE-modified fibers/HDPE, and (c) TMPE-modified fiber/HDPE.

![Figure 8](image2.png) **Figure 8:** Bending performance of (a) HDPE and HDPE composites filled with (b) original fibers, (c) MPE-modified fibers, and (d) TMPE-modified fibers.

![Figure 9](image3.png) **Figure 9:** Impact performance of HDPE composites filled with PET/cotton fibers.
The reinforcing effect of TMPE-modified fibers is much higher than that of unmodified fibers, which indicates that TMPE modifier has obvious improvement effect on the properties of composites. On the one hand, the modified coating makes the surface of the fibers rougher and increases the contact area between the fibers and the matrix, which can increase the compatibility of the fibers and the matrix; on the other hand, the modified coating protects the fibers and reduces the carbonization degree of the fibers, thereby significantly improving the mechanical properties of the conforming material.

4 Conclusion

In summary, the direct utilization of hybrid PET/cotton hybrid fibers was studied to enhance HDPE composites, so as to avoid the separation of the fibers and attendant environmental problems. Also, the surface modification of the fibers was carried out successfully to improve their thermal stability and strengthen their enhancing. TGA and color difference analysis showed the synthesized TMPE modifier increased the thermal stability of the fibers and the fibers-filled HDPE composites. Moreover, the breaking force of TMPE-modified fibers is also improved. Compared with the original fibers-filled composites, the bending strength, modulus, and impact strength of TMPE-modified fibers/HDPE composites were increased by 31.7%, 25.7%, and 89.1%, respectively.

Funding information: Authors state no funding involved.

Author contributions: Wei Cao: writing – original draft, conceptualization, data curation, software, methodology; Qiuying Li: conceptualization, formal analysis, validation, visualization, project administration, writing – review and editing; Chifei Wu: resources, supervision, funding acquisition, validation, investigation.

Conflict of interest: Authors state no conflict of interest.

References

(1) Nørup N, Pihl K, Damgaard A, Scheutz C. Evaluation of a European textile sorting centre: material flow analysis and life cycle inventory. Resour Conserv Recy. 2019;143(32):310–9.
(2) Haslinger S, Hummel M, Anghelescu A, Määtännös M, Sixta H. Upcycling of cotton polyester blended textile waste to new man-made cellulose fibers. Waste Manage. 2019;97(25):88–96.
(3) Sun XW, Lu CH, Zhang W, Tian D, Zhang X. Acetone-soluble cellulose acetate extracted from waste blended fabrics via ionic liquid catalyzed acetylation. Carbohydr Polym. 2013;93(1):405–11.
(4) Shi S, Zhang ML, Ling C, Hou WS, Yan ZF. Extraction and characterization of microcrystalline cellulose from waste cotton fabrics via hydrothermal method. Waste Manage. 2018;82(30):139–46.
(5) Felice Q, Sara V, Simone W, Klemens K, Lukas S, Alessandro P, et al. Highly selective enzymatic recovery of building blocks from wool-cotton-polyester textile waste blends. Polymers. 2018;10(10):1107.
(6) Palme A, Peterson A, Motte H, Thelander H, Brelied H. Development of an efficient route for combined recycling of PET and cotton from mixed fabrics. Textile & Sustainability. 2017;3(1):26–35.
(7) Li Z. Separation of waste cotton-polyester blended fabric. Mater Sci Eng. 2020;768(2):022062–7.
(8) Haule LV, Carr CM, Rigout M. Preparation and properties of regenerated cellulose fibers from cotton waste garments. J Clean Prod. 2016;112(5):4445–51.
(9) Stoeva K, Alriksson S. Influence of recycling programmers on waste separation behaviour. Waste Manage. 2017;68(1):732–41.
(10) Haslinger S, Hummel M, Anghelescu-Hakala A, Määtännös M, Sixta H. Upcycling of cotton polyester blended textile waste to new man-made cellulose fibers. Waste Manage. 2019;97(31):88–96.
(11) Yang G, Park M, Park S-J, Li Z. Recent progresses of fabrication and characterization of fibers-reinforced composites: a review. Compos Commun. 2019;14(4):34–42.
(12) Lertwassana W, Parnklang T, Mora P, Jubsilp C, Rimdusit S. High performance aramid pulp/carbon fiber-reinforced polybenzoxazine composites as friction materials. Compos Part B-Eng. 2019;177(24):107280–90.
(13) Raphael NA, Namratha KA, Chandrasheker BN, Sadasivuni KKC, Ponnamma DD, Smitha ASE, et al. Surface modification and grafting of carbon fibers: a route to better interface. Polym Cryst Growth Ch. 2018;64(3):75–101.
(14) Lucas L, Victor HC, Silvia HPB. Reuse of p-aramid from industrial waste as reinforcement fiber in polyamide 6.6. Polym Test. 2016;56(37):124–30.
(15) Li S, Han KQ, Rong HP, Li XZ, Yu MH. Surface modification of aramid fibers via ammonia-plasma treatment. J Appl Polym Sci. 2014;131(10):40250–6.
(16) Chen JR, Zhu YF, Ni QQ, Fu YQ, Fu XS. Surface modification and characterization of aramid fibers with hybrid coating. Appl Surf Sci. 2014;321(1):103–8.
(17) Vasilica P, Augustin M, Ovidiu C, Gabriela L, Emil IM, Corneliu M, et al. Tinctorial response of recycled PET fibers to chemical modifications during saponification and aminolyis reactions. Ind Eng Chem Res. 2014;53(43):16652–63.
(18) Fang YC, Liu XY, Tao X. Intumescent flame retardant and anti-dripping of PET fabrics through layer-by-layer assembly of chitosan and ammonium polyphosphate. Prog Org Coat. 2019;134(48):162–8.
(19) Mao YP, Li QY, Wu CF. Surface modification of PET fiber with hybrid coating and its effect on the properties of PP composites. Polymers. 2019;11(10):1726–41.