Effect of Bamboo Charcoal Content on the Heat Preservation Performance of Bamboo Charcoal / PET Blended Fibers

Ta-Chung An[a, b], Chin-An Lin[b], Chao-Huei Liu[a], Pei-Ti Hu[a]

[a] *Department of Raw Materials and Yarn Formation, Taiwan Textile Research Institute, Taipei 23674, Taiwan (R.O.C.)*
[b] *Graduate Institute of Textile Engineering, Feng-Chia University, Taichung 40724, Taiwan (R.O.C.)*

Abstract

The bamboo charcoal material was added in polyethylene terephthalate (hereafter referred to as PET) fiber spinning process in various proportions controlled at 0.5, 1.0, 1.5, 2.0 and 2.5% by weight to compose bamboo charcoal / PET blended fibers (hereafter referred to as BCE). The halogen light radiation method and the Thermo-vision analysis were applied to estimate the effect of bamboo charcoal content on the heat preservation performance of BCE. For a comparison, a carbon black / PET blended fiber (hereafter referred to as CBE) with a content of 1.5wt% commercial dope dyed carbon black material was utilized. The result indicated that BCE in all compositions showed a better heat preservation performance than CBE, and the 1.5wt% BCE achieved the highest value of relative heat preservation of 0.44℃. In addition, the removal test of ammonia gas revealed that BCE had a better removal effect than CBE, the reduction rates for ammonia gas in 100ppm primary concentration of 1.5wt% BCE and 1.5wt% CBE were 48% and 18%, respectively.

Keywords: Bamboo charcoal; Blended fiber; Carbon black; Relative heat preservation; Removal test

Introduction

Bamboo charcoal becomes more and more renowned in our daily lives. Owing to the multi-porous structure and high specific surface area of bamboo charcoal (shown in Figure 1 [1]), it gives good adsorption performance, removal effect for harmful gas and moisture adjustment capability [2-7], the far infrared way emission and electromagnetic shielding potential of bamboo charcoal itself have also been examined [8]. Sakada [9] investigated the adsorption for various gases of bamboo charcoal in a pore size range of 0.25~0.40nm, found that the pore size of bamboo charcoal influenced the adsorption performance for different gases, the adsorption for N_2 and CH_4 were not obvious, in contrast, the same bamboo charcoal showed a good removal effect for N_2O and CO_2. Asada [10] suggested the bamboo charcoals should be classified according to their carbonizing temperature since the removal capability of harmful gases was highly relative to the effective carbonizing temperature. Mizuta [11] compared the effectiveness of adsorption in removal of nitrate-nitrogen of bamboo charcoal and commercial activated carbon, the result indicated that the adsorption effectiveness of bamboo charcoal for nitrate-nitrogen was higher than that of activated carbon.

High quality bamboo charcoal made from careful procedure can be used in lots of applications including filtration materials, cosmetics, beddings, apparels, textile accessories, and so on. Due to the raise of health consciousness of commonalty, a variety of end products containing bamboo charcoal have been developing actively, which initiates research works with regard to bamboo charcoal contained within synthetic fiber technologies and applications.

The topic of functional synthetic fiber has become a high value-added technology in man made fiber industry. Different functional materials were investigated for creating various functional fibers, the performances of those fibers were also been studied extensively. People are becoming ever more aware of safety, health, cleanliness and comfort, there is a great demand for fibers which improve the quality of life, and help people pursue their chosen lifestyle [12]. Functional fibers have taken up a position and been widely promoted in man made fiber market. These functions include anti-bacteria, anti-static, UV-cut, far infrared way emission, flame retardant, etc.

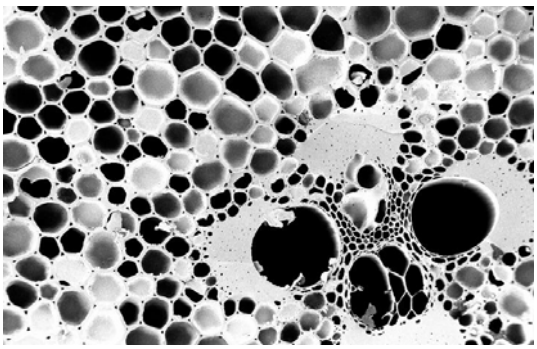

Fig. 1. The multi-porous structure of bamboo charcoal (Magnification: 500×)

In this study, bamboo charcoals carbonized reach upwards of 750℃ in a specific kiln was used. Through a series of accurate milling procedure and compounding process, the master-batch with 10wt% concentration of bamboo charcoal within PET matrix was manufactured and was then added in PET fiber spinning process to prepare fiber samples with different effective contents of bamboo charcoal as 0.5, 1.0, 1.5, 2.0 and 2.5wt%. The effect of

bamboo charcoal content in PET fiber on the heat preservation performance was estimated by the halogen light radiation method and the Thermo-vision analysis. In order to confirm the outstanding activity of bamboo charcoal, a PET fiber sample containing 1.5wt% carbon black additive was utilized for a comparison. Moreover, a removal test for ammonia gas of 1.5wt% bamboo charcoal and 1.5wt% carbon black within PET was carried out, from which the adsorption performance of bamboo charcoal was preliminary examined.

Experimental

Materials

1.Bamboo charcoal

The bamboo charcoal was made from Moso bamboo (*Phyllostachys pubescens*) material carbonized in a charcoal kiln. The temperature sensors were installed inside the kiln and the temperature of each sensor was monitored. The bamboo material was carbonized at 750℃ for 1 hour and was then left to cool in the kiln. The bamboo charcoal was then moved out of the kiln, through the crushing, milling and sieving procedure, a bamboo charcoal powder with a D_{50} average diameter of 1 micron measured by Beckman Coulter N4 Plus analyzer was obtained.

2.PET

PET chips for master-batch manufacturing and for fiber spinning were provided by Shinkong synthetic fibers Co., Ltd. The intrinsic viscosity = 0.640 dl/g, the polydispersity index = 2.09, melting point = 255.7℃.

3.Carbon black master-batch

Commercial dope dyed carbon black master-batch (Clariant Renol-Black ATX439) was used for spinning with PET to compose CBE fiber sample with a content of 1.5wt% carbon black. The concentration of carbon black in master-batch is 30wt%.

Production method of blended fiber

Bamboo charcoal / PET master-batch was manufactured by the twin screw compounding machine (ThermoHaake Rheomex PTW25); the concentration of bamboo charcoal in master-batch was controlled at 10wt%. The intrinsic viscosity of master-batch was 0.50 dl/g, melting point was 250.3℃. Before fiber spinning process, PET chips and master-batches were dried at 125℃ for 8 hours under nitrogen separately in order to control the moisture content of both materials below 30ppm.

A loss-in-weight type metering device was utilized for accurately feeding master-batches into extruder according to the set blending proportions. The melt spinning pilot equipment was 8-end industrial scale, and the 48-hole/end spinnerets were used, with a capillary L/D of 0.50/0.25, the spinning parameters were as follows: the throughput of polymer was 44g/min/end, spinning temperature was 290℃, take-up speed was 3000m/min.

The feeding proportions of master-batches to the whole blended polymer were controlled at 5, 10, 15, 20 and 25wt%; so that the bamboo charcoal effective contents in blended fibers were 0.5, 1.0, 1.5, 2.0 and 2.5wt%. Simultaneously, a commercial dope dyed carbon black master-batch was blended spun with PET in 1.5wt% carbon black content as a comparative sample.

Sample preparation

BCE and CBE fibers were processed by a hot-draw knitter (Lawson-Hemphill, LH-123 HDK) with the same draw ratio of 1.50 to compose a fiber knit structure, 10cm×10cm specimens were prepared from such knit fabrics for estimation of relative heat preservation and gas removal effect. Table 1 lists the compositions of fiber knit specimens.

Table 1 Composition of fiber knit specimen

Fiber Knit Specimen No.	Bamboo charcoal content in fiber (wt%)	Carbon black content in fiber (wt%)
BCE05	0.5	NA
BCE10	1.0	NA
BCE15	1.5	NA
BCE20	2.0	NA
BCE25	2.5	NA
CBE15	NA	1.5

Measurements

1.Denier of as-spun fiber

The deniers of fiber samples were measured by preparing skeins of 90-meter length of fiber on a wrap roll and weighing it accurately with the help of a sensitive electronic balance, and then the denier value could be calculated. The denier values reported are the average of measurements carried out on five samples prepared from each fiber sample.

2.Tensile property of as-spun fiber

Load-elongation characteristics of the as-spun fibers at room temperature were obtained with the help of automatic tensile tester (Textechno, Statimat-C) using samples of 250 mm length and an extension rate of 1,200 mm/min.

3.Color measurement of fiber knit specimen

The whiteness (W) of as-spun fiber was calculated by equation (1), where L*, a*, and b* values were determined by spectrophotometer (Datacolor, SF600 Plus-CT) according to the CIE color system. The W value reveals the alteration of surface color of specimen. Consequently, a much lower W of BCE or CBE was obtained due to black color additives were blended in the original white PET matrix.

$$W = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2} \quad (1)$$

4.Heat preservation estimation

The Thermo-vision 900 infrared camera analysis system was used to measure the heat preservation value of fiber knit specimen. The set heat source was 500W halogen light. The heat source distance was 100cm. The radiation time was 10 minutes. Figure 2 illustrates the testing elements for heat preservation analysis.

The concept of “relative heat preservation” was suggested for emphasizing the comparatively higher heat preservation effect among testing specimens. Therefore, each test was carried out by

measuring one BCE specimen versus CBE15 specimen simultaneously for comparing heat preservation behavior objectively, and the CBE15 was employed as a comparative object. There were five sets of test performed in this study: BCE05 vs. CBE15; BCE10 vs. CBE15; BCE15 vs. CBE15; BCE20 vs. CBE15 and BCE25 vs. CBE15.

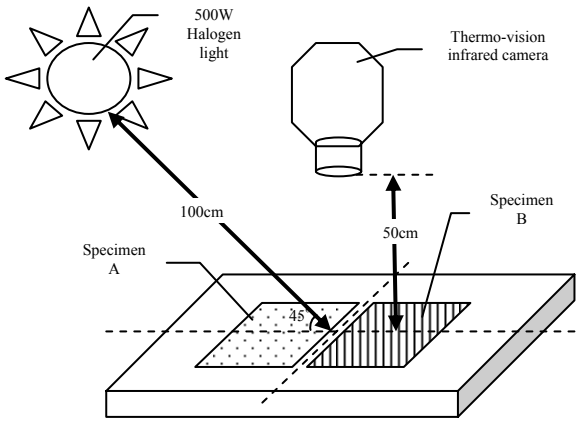

Fig. 2. Scheme of testing elements for heat preservation analysis

The testing procedure was as follows: A duo of fiber knit specimens were placed on testing plate side by side, the surface temperatures of specimens before radiation were measured by Thermo-vision, recorded as T_{0b} and T_{0c} for BCE and CBE, respectively. The 500W halogen light was then turned on to illumine both specimens for 10 minutes and turned off subsequently. T_{1b} and T_{1c} data was recorded as the surface temperatures of BCE and CBE on the point of 30 seconds subsequent to the light was turned off. Consequently, the difference of T_{1b} and T_{0b} represents the heat preservation of BCE specimen, and the difference of T_{1c} and T_{0c} represents the heat preservation of CBE specimen. The relative heat preservation, $\triangle$Tp, was defined as the difference between the heat preservation of BCE and CBE specimens, calculated as equation (2),

$$\triangle Tp = (T_{1b} - T_{0b}) - (T_{1c} - T_{0c}) \quad (2)$$

5.Ammonia gas removal test

The removal test was tested in a 5-liter sampling bag (Tedlar bag, GL Sciences Inc., Tokyo, Japan) [10] in accordance with the deodorization evaluation test method of JAFET in Japan. The specimen was placed in the sampling bag and a sealing clip isolated the specimen. Nitrogen was pumped into the sampling bag and then the ammonia gas with an initial concentration of 100ppm was added to the sampling bag using a gastight syringe. The prepared sampling bag was incubated at 20 ℃. After the gas concentration in the sampling bag stabilized, the specimen and gas was mixed by opening the sealing clip. The time mixing for the specimen and ammonia gas was initially 0. The concentration of the gas in the sampling bag was determined after 1 hour, recorded as C1. The gas removal effect of specimen could be presented by the reduction rate (R%) of ammonia gas, which was defined as equation (3),

$$R\% = [(100 - C1)/100] \times 100\% \quad (3)$$

Results and Conclusions

The denier of a 48-filament bundle of as-spun fiber is controlled at 132±1 de. The tenacity and elongation testing results for as-spun fibers of pure PET and additives added-in PET are shown in Figures 3 and 4. It can be seen from Figure 3 that the tenacity decreases with increasing the blended proportion of bamboo charcoal or carbon black in PET, this may be attributed to the segregated group of particles could be a stress concentrator which leads to premature failure [13]. In the cases of 0.5 and 1.0wt% of bamboo charcoal content, the tenacity decreases slightly, but when the content is above 1.5wt%, it shows a more obvious decreasing tendency. The same behavior can be also observed in 1.5wt% carbon black case.

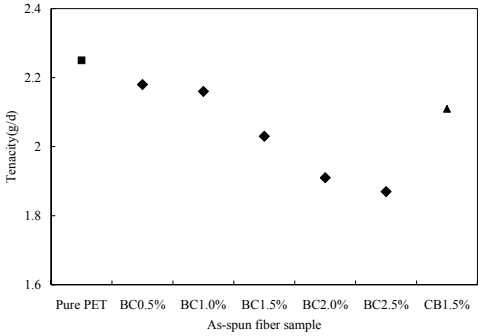

Fig. 3. Tenacity of as-spun fiber sample
(BC: Bamboo Charcoal; CB: Carbon black)

Figure 4 indicates the existing bamboo charcoal in PET could alter the breaking elongation of as-spun fiber. In the cases of lower contents (0.5~1.0wt%), the bamboo charcoal particle reduces the elongation of as-spun fiber to break, which is related to the increasing spinline elongational viscosity induced by the addition of fillers [13]. It is found that an elevated tendency of breaking elongation as the blending proportion of bamboo charcoal higher than 1.5wt%, which may be interpreted as hydrodynamic particle effect, the excess filler contained in spinline results in a greater spinline instability; which may be also ascribed to the heat preservation performance of bamboo charcoal material, increases the content of bamboo charcoal would raise the spinline temperature, that incurs a relatively poor orientation of molecular chains in as-spun fiber, a higher breaking elongation would be obtained. In the case of 1.5wt% carbon black content, the breaking elongation is slightly lower than pure PET sample, which may be considered that there is no obvious temperature raising effect of 1.5wt% carbon black contained as-spun fiber.

Table 2 indicates the color measurement result of pure PET, BCE and CBE fiber knit specimens. L* represents the lightness intensity, and a*, b* implicate color values on a red-green axis and a blue-yellow axis, respectively. The W value was calculated according to L*, a* and b*, which denotes the whiteness level of a sample. It is found that W decreases with increasing blending proportion of additives. Because of the black color of bamboo charcoal, increases the amount of bamboo charcoal in PET causes the gradually darker appearance of the fiber knit specimen. The W of CBE15 is between the values of BCE15 and BCE20, which means the color appearance of specimen containing 1.5wt% carbon black, is similar to 1.5wt% or 2.0wt% of bamboo charcoal content.

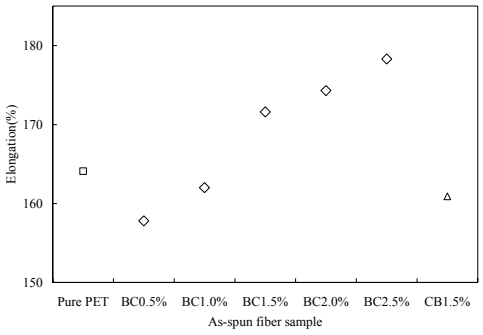

Fig. 4. Elongation of as-spun fiber sample
(BC: Bamboo Charcoal; CB: Carbon black)

Table 2 Color indices of fiber knit specimen

Fiber Knit Specimen No.	L*	a*	b*	Whiteness (W)
Pure PET	89.5	-1.5	2.3	89.1
BCE05	30.4	1.0	1.8	30.4
BCE10	22.4	0.8	1.4	22.4
BCE15	20.6	0.6	0.7	20.6
BCE20	18.8	0.4	0.4	18.8
BCE25	18.3	0.4	0.2	18.3
CBE15	19.5	0.2	0.3	19.5

From the halogen light radiation and Thermo-vision analysis, the heat preservation function of BCE could be estimated preliminarily. The CBE15 specimen was used as a comparative object to exhibit the distinctive performance of BCE. Five sets of comparison tests were carried out, shown in Figure 5. Both of BCE and CBE raise the surface temperature after radiation of halogen light, the heat preservation data higher than 4.3℃ for all sets of specimens, which may be related to the effect of high thermal conductivity as well as low specific heat additives. Nevertheless, BCE specimens in all compositions showed a better heat preservation effect than CBE15. It is found that the relative heat preservation (△Tp) alters with variation of the specimen composition. Specimen with a low content of 0.5wt% bamboo charcoal displays almost the same heat preservation level as CBE15, as the content of bamboo charcoal more than 1.0wt%, a noticeable superior performance of heat preservation can be observed, and the highest △Tp of 0.44℃ appears in the examination of BCE15 versus CBE15.

It is worth mentioning that the data obtained from the 20~25wt% specimens reveal lower △Tp than 10~15wt% cases, which may be considered as the intervention of excess addition of bamboo charcoal, the effect of ascending thermal conductivity makes fiber knit specimen easily conduct the heat so that the heat retaining ability is comparatively poor.

Examine the whiteness of fiber knit specimen, it is known that the color appearance of CBE15 approximates to BCE15 or BCE 20, but from the △Tp computation in Figure 5, it clearly points out that an enhanced heat preservation effect coming from bamboo charcoal. The heat preservation performance may not only depend on the color appearance, but also relate to the materials themselves, this observation may need a further ascertain.

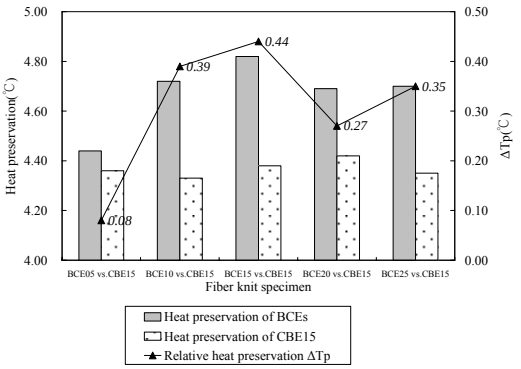

Fig. 5. The heat preservation performance of BCE and CBE

Gas removal test is in accordance with the deodorization test evaluation method of JAFET in Japan. BCE15 and CBE15 were selected for the evaluation of ammonia gas removal effect, and the testing result is shown in Figure 6. Carbon black 1.5wt% contained in PET sample has less adsorption effect for ammonia, its reduction rate is just 18%; but the bamboo charcoal / PET fiber knit with the addition of 1.5wt% content has remarkable ammonia adsorption effect, its reduction rate reaches 48%. It can be concluded that after the fiber is added with bamboo charcoal, the fiber has the gas removal effect by the function of multi-porous structure and high specific surface area of bamboo charcoal. It is known from the report of adsorption characteristic of bamboo charcoal given by Sakada [9] and others: the pore size of bamboo charcoal is a broadly distribution from nano-scale to micro-scale, and the ultrafine pore distribution of bamboo charcoal is mainly between 0.25 and 0.4nm; the size of the ammonia molecule is about 3.8Å, so it can be deduced that the adsorption effect for ammonia is due to the multi-porous structure of numerous fine (8~20Å) and ultrafine pores (smaller than 8Å) of bamboo charcoal. Although bamboo charcoal is proportionally added in PET matrix for fiber formation, there are partial particles of bamboo charcoal exposed on the surface of fiber, which still gives play to adsorb ammonia and has the deodorization effect.

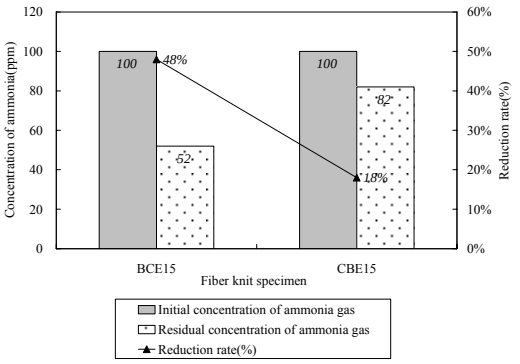

Fig. 6. Removal effect for ammonia gas of BCE15 and CBE15

Conclusions

It is found that the bamboo charcoal / PET fibers indeed have the excellent heat preservation characteristic, the temperature raising effect is approximately increased with the increase of the added bamboo charcoal, a 1.5wt% content pf bamboo charcoal exhibit the best heat preservation performance, considering the spinning efficiency and tensile property of the as-spun fiber, it is suggested that 1.0~1.5wt% of bamboo charcoal added in PET fiber formation process is the optimum composition.

It is also found in the ammonia removal test, the bamboo charcoal / PET fiber certainly has the greater adsorption ability for ammonia gas than commercial dope dyed carbon black material, this specialty is mainly contributed by the function of multi-porous structure and the high specific surface area of bamboo charcoal.

There are several objects should be continuously studied. Although a preliminary conclusion of the heat preservation performance of bamboo charcoal has been examined, the influence of various specific surface area of bamboo charcoal on the textile function requires further discussion. The alteration of characteristics of bamboo charcoal contained fabric after dyeing and finishing needs to be clarified. Moreover, a non-circular fiber cross-section may be a topic worth to be investigated. The fiber with the cross-section of round shape can be replaced by those with different cross-sections or that with the hollow cross section and micro-crater surface, in order to enlarge the fiber surface area for increasing the probability of exposing the bamboo charcoal powders to the fiber surface, and further promote the adsorption characteristic of bamboo charcoal / synthetic fibers.

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