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Full Length Research Paper

Medical effects of poly-ethylene terephthalate (PET) non-woven fabrics treated with bamboo activated charcoal

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In this study, bamboo activated charcoal was mixed with acrylic resin in various proportions and deposited on poly-ethylene terephthalate (PET) non-woven fabrics. A series of characterizations were carried out to estimate the performances of PET non-woven fabrics such as far infrared ray emission, heat retention, negative ions, deodorization of ammonia gas and tenacity. The results obtained indicate that the temperature difference on the surface of treated non-woven fabrics after exposure to a halogen lamp was between 4.28 to 8.26°C. The test for negative ions demonstrated that the concentration of negative ions released from treated non-woven fabrics was 420 to 630 ions/cm^3. The deodorization rate of the treated non-woven fabrics was found to be between 85 to 92% and the rate was the same for 5 and 10 g/L of bamboo activated charcoal addition. An increase in resin concentration increased the abrasion strength and tensile strength; and reduced the tear strength of the treated non-woven fabrics. The bamboo activated charcoal concentration exhibited no effect on the physical properties of the treated non-woven fabrics.

Key words: Poly-ethylene terephthalate (PET), non-woven fabrics, bamboo activated charcoal, far infrared ray, negative ions, deodorization.

INTRODUCTION

Bamboo is an abundant and inexpensive natural resource in China. Bamboo charcoal (BC) is produced from the rapidly growing moso bamboo plants, which are distributed widely in China. The bamboo charcoal is low cost, and its price is only about 1/3 to 1/5 of that of activated carbon (AC) in China (Wang et al., 2010). The study of bamboo charcoal has recently become a popular field in China (Cheng et al., 1999) and Japan (Kimura et al., 2002). Mizuta et al. (2004) found that the adsorption effectiveness of BC was higher than that of AC in removing nitrate-nitrogen from water. BC is effective in removing nitrate–nitrogen from underground and surface water, so that the performance of water treatment using BC is considered to be more stable than the same processes using activated carbon. BC has become popular recently due to its excellent characteristics of absorption, moisture regulation, anti-bacterial property, deodorization property, and generation of far infrared ray and negative ions (Lou et al., 2007). Several studies have found that bamboo charcoal has excellent adsorption capacity for a wide variety of substances, such as nitrate-nitrogen (Mizuta et al., 2004), heavy metals (Wang et al., 2010, 2008), dibenzothiophene (Zhao et al., 2008) and harmful gases (Asada et al., 2006; Chuang et al., 2008); it can be used for the purification of water or air.

Bamboo activated charcoal can also produce infrared rays suitable for absorption by the human body, thereby keeping the body warm and accelerating blood circulation (Wang et al., 2006). Further, bamboo activated charcoal increases the number of negative ions, which are

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beneficial to human health, and can refresh air. Bamboo activated charcoal can also be utilized as a mesh for cleaning water and air through its excellent absorption properties, and it has been the subject of many studies (Mizuta et al., 2004; Abe et al., 2001). Moreover, bamboo charcoal could be chemically modified and conjugated with protein antigens for subsequent isolation of the specific antibody-bearing B-cells (Lin et al., 2010). Some believe that bamboo activated charcoal has many beneficial properties that could be widely applied in industries such as in agriculture, electronics, medicine and healthcare, food processing, environmental protection and in the textile industry.

Non-woven fabrics unlike traditional fabrics, are fabricated by crossing fibers on one plane surface in four directions, and have good physical properties. Non-woven fabrics can be generated using different techniques including needle punching, needle bonding, spun bonding, melt bonding, chemical bonding and heat bonding. These different production techniques are used in different fields (Ghosh and Chapman, 2002; Sang et al., 2005; Wang, 1999; Dedov, 2004a, 2004b; Lukic and Jovanic, 2004). Non-woven fabrics are commonly applied in medicine and healthcare, and its utilization could change from the reusable to disposable products. Non-woven fabrics are chiefly applied in medicine, healthcare and for filtering (Wang and He, 2007). Furthermore, the present study will be aimed at fabricating the chitosan, which is a biodegradable and antibacterial polymer, onto poly (N-isopropylacrylamide) (PNIPAAm) gel/polypropylene (PP) non-woven composites surface for wound dressing applications (Chen et al., 2005). Non-woven pads were prepared using cotton and other natural replacement of synthetic sorbents to compare their oil sorption capacities (Choi et al., 1996). Due to the evolutions and improvements in materials science and of seeking for better life, the functional composites attract more and more attention. In dairy life, heavy air pollution make our living environment get worse, it also drifts the negative-ion toward dissipation and produces excess amount of positive-ion. The developments on negative-ion from functional Bamboo charcoal are absolutely good for human health. In recent years, non-wovens for medical utilities have been directed to disposal products. Our present study aims at the medically disposal non-wovens and health-care clothes.

Accordingly, this study applied multi-functional bamboo activated charcoal to non-woven fabrics, followed by processing using resin to facilitate attachment of bamboo activated charcoal to the surface of non-woven fabrics to increase the functions of non-woven fabrics. The physical properties, release of far infrared ray and negative ion and deodorization property of the treated non-woven fabrics were assessed to determine whether bamboo activated charcoal could improve the non-woven fabrics functions or not. We expect bamboo activated charcoal on non-woven fabrics can be applied in medicine and healthcare.

MATERIALS AND METHODS

Bamboo activated charcoal (Sample size : 60 μm) and Acrylic resin were obtained from Vresicolor Skyscience and Technologies Co. and Ming Yuh Enterprise Co., respectively, and were used as received. The PET needle punching non-woven textiles, base weight 100 g/m^2, was supplied by Cannpox Enterprise Co., Ltd. The scouring agent or laundry detergent (Lipofol TM-1000E) was supplied by Taiwan Nicca Chemical Industrial Co., Ltd., Taipei, Taiwan.

The PET non-woven fabrics were cut to the size, measuring 28.5 × 20 cm, followed by soaping with 2 g/L scouring agent liquor at 80°C for 20 min. After soaping it was subjected to washing twice in water and then dried at 65°C for 10 min. Different ratios of bamboo activated charcoal solution (2.5, 5, 10, and 20 g/L) were dredged over PET non-woven fabrics through a mesh screen which size is 80 μm. Acrylic resin in different concentrations (5, 10, 15 ows %, ows is on the weight of solution) was sprayed using a spray nozzle control at pressures of 1.38 MPa onto PET non-woven fabrics to fix bamboo activated charcoal through back and forth. The treated PET non-woven fabrics were placed in an oven and dried at 90°C for 15 min. Then, the treated PET non-woven fabrics were tested in order to estimating their physical properties, release of infrared rays and negative ions, and deodorization function, etc.

Physical and mechanical property test

Softness test

The treated PET non-woven fabrics were tested for physical properties according to the following criteria. The softness of treated non-woven fabrics was tested according to the protocol described in the ASTM D1388-96 methods. Softness was recorded on an Inteco machine with a 41.5°C slant. The specimen was placed on a horizontal platform with 1 inch in length and 8 inches in width, and above and adjacent to the edge of the platform there are one plastic ruler and one inclined plane with inclined angle of 41.5°, respectively. During testing, one can push out the specimen by means of shifting the plastic ruler towards the edge direction of the platform, where the inclined plane is attached, until the specimen can touch down the inclined plane. As a result, the hang-length of the specimen will be determined from the plastic rule to estimate its softness.

Surface abrasion test

The Surface abrasion of treated non-woven fabrics was tested according to the protocol described in the ASTM D4966-98 methods. A specimen with 3.8 cm in diameter was firmly mounted in the holder of Martindate Abrasion tester. During testing, the specimen will be subjected to continuous abrasion from the worsted wool fabrics, upon which a loaded pressure of 12.0 kPa will be added, until the specimen is broken and the times of abrasion cycle will be also recorded.

Tear strength test

The tear strength of treated non-woven fabrics was tested according to the protocol described in the ASTM D1424-09 methods. Tear strength was measured by Seisakusho machine. The fabrics sample for the tear test will be 10 cm in length and 6.3 cm in width. At the middle of the edge along the length direction of

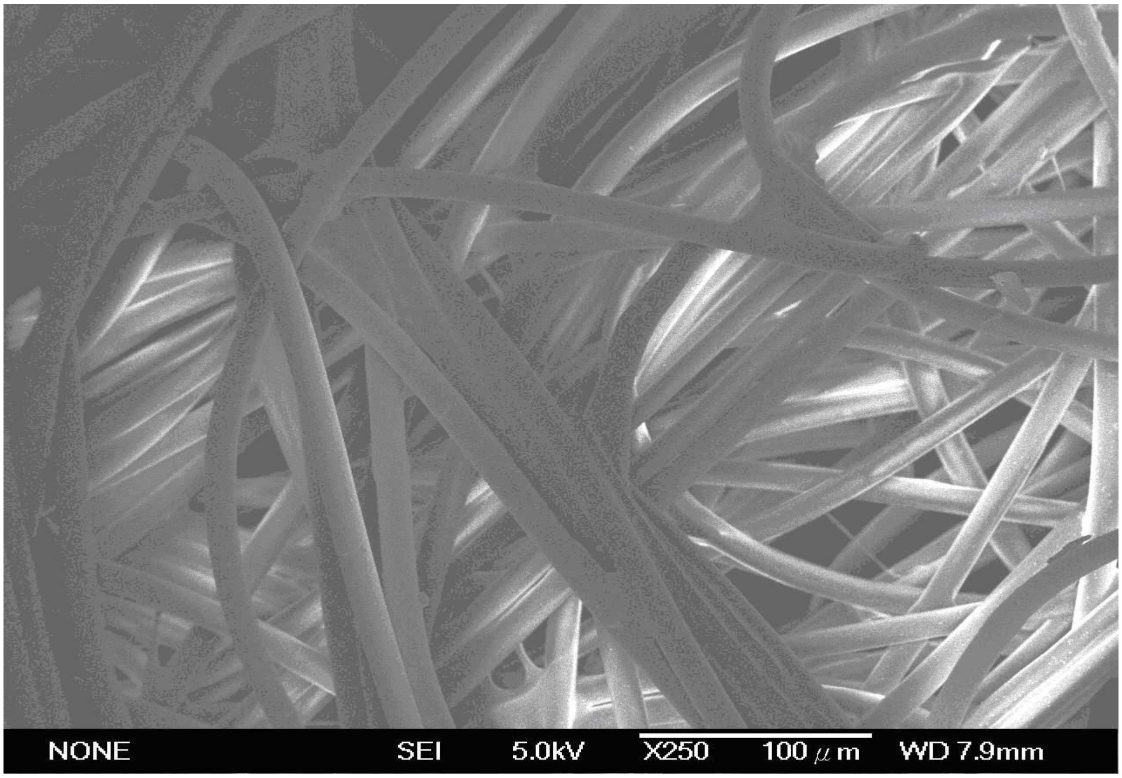

Figure 1. The SEM image of unprocessed non-woven fabrics (x250).

the sample there is a sharp notch dip, where a notch with 2 cm in length was produced. During the tear strength testing, this sample was mounted in the sample holder of a tear strength tester, and the tear strength was recorded while the pendulum was falling down to tear out the sample of the fabrics.

Tensile strength test

The tensile strength of processed non-woven fabrics was tested according to the protocol described in the ASTM D5034-09 methods. Tensile strength was measured by Hung Ta HT-9102 machine. A sample is 6 inches in length and 4 inches in width, and it will be clamped firmly with the clamps of the Grab tester. During tensile testing, this fabric sample was subjected to a constant rate of extension until it could be broken down, and the ultimate tensile strength (*UTS*) of the sample was determined.

Warmth retention ability test

The warmth retention ability of processed non-woven fabrics **t**est was exposed to a 500 W halogen lamp with 100 cm distance. An infrared image thermometer (Thermovision) was used to obtain thermal images at 50 cm apart from the fabrics. By analyzing the surface temperature of test fabrics, the temperature rising effects of test fabrics could be obtained.

Negative ion property test

The negative ion property of treated non-woven fabrics test was placed into a test case size is 300 mm* 200 mm* 200 mm at 20°C and 65% R.H. The negative ion concentration of the composites was measured by an ion concentration measuring system. Negative ion property was measured with a negative ions counter (ITC201A). Two samples were contacted closely and rubbed with each other at the linear velocity of 300 ± 5 cm/min to produce positive and negative ions, and then the ion concentration was detected.

Deodorization property

The deodorization property of the treated non-woven fabrics test was carried out according to JAFF deodorization function test methods. A 10cm*10cm test sample was placed into a 5 L-Tedlar bag containing ammonia gas of an initial concentration of 100 ppm. The detection tube was then used to detect the variation of the concentration. The test time was 1 h. Deodorizing rate calculation equation is as follows, Deodorizing rate (%) = [(blank specimen test value- specimen test value)/ blank specimen test value] ×100%.

RESULTS AND DISCUSSION

Surface structure and TGA analysis of treated non-woven fabrics

Figure 1 presents the SEM images of untreated non-woven fabrics under different magnifications. The images indicate that the fabric surface is smooth and homogeneous. Figure 2 presents the SEM images of non-woven fabrics treated with 5% resin and 20 g/L bamboo activated charcoal. These images

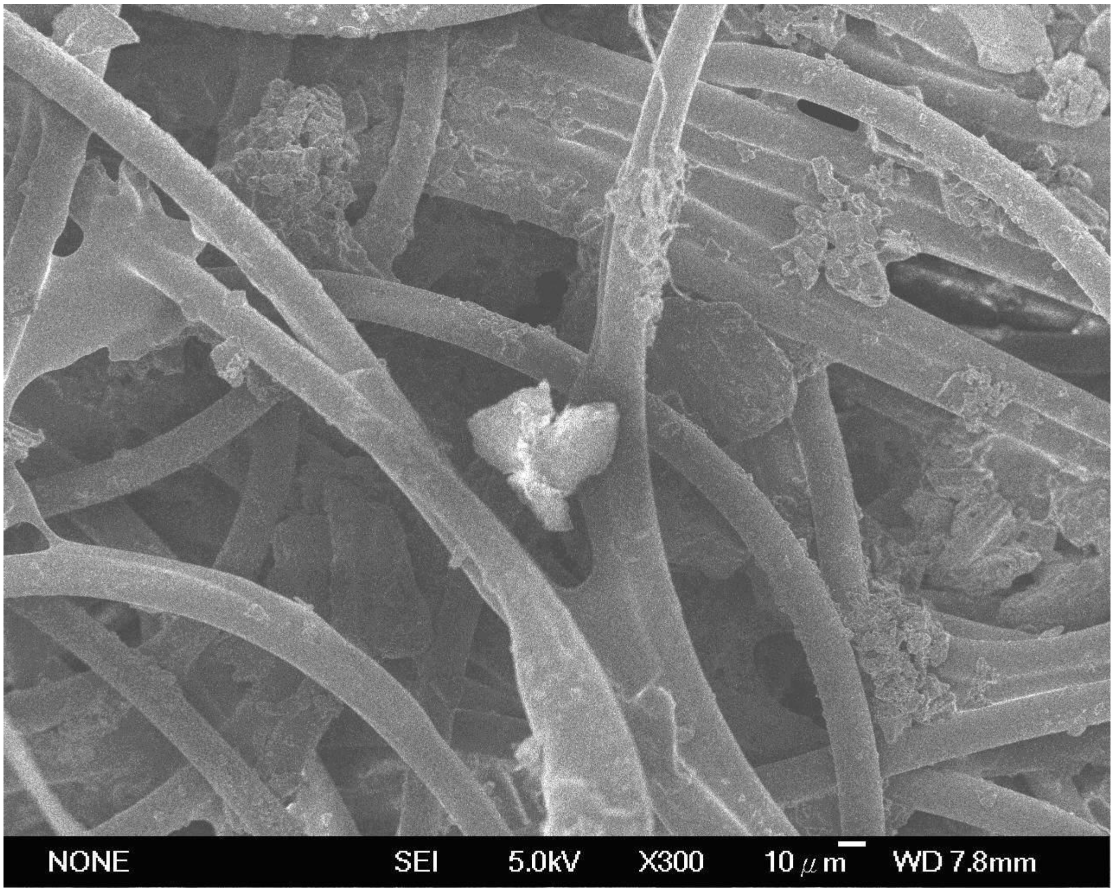

Figure 2. The SEM image of non-woven fabrics processed in 5% resin, 20 g/L bamboo charcoal (x250).

Table 1. The TGA analysis data of processed non-woven fabric by different condition.

Item	T_d^{10} (°C)	T_d^{2nd} (°C)	700°C [(1)] (%)
untreated	410.8	485.9	0.83
C2.5R15	403.2	480.8	1.31
C5R15	396.0	472.0	1.66
C10R15	380.0	465.9	2.53
C20R15	365.4	453.4	5.66

T_d^{10} means that the decomposition temperature of processed non-woven on 10% of decomposition; T_d^{2nd} means that the second stage decomposition temperature of processed non-woven; [1)] means that the residue amount under 700°C decomposition temperature of processed non-woven.

demonstrate that the bamboo activated charcoal was attached to, and distributed on, the fiber surface by resin.

The thermal stabilities of the untreated non-woven fabrics and that treated with different concentrations of activated bamboo charcoal were conducted using TGA instrument. In order to investigating the effect of concentration of the activated bamboo charcoal on the degradation behavior, all the resin concentrations were kept in less than 15%. As shown in Table 1 and Figure 3, the T_d temperature for the untreated PET fabrics is 410.8°C. However, as the concentration of activated bamboo charcoal was increased from 2.5 to 20 g/L, the thermal degradation temperature of the treated fabrics would decrease from 403.2 to 365.4°C, suggesting that a porous structure in the binding layer of the activated bamboo charcoal could be resulted in as the concentration increased and this structure would in turn increase the ability in heat dissipation. Moreover, a second stage of thermal degradation would be observed in the treated PET non-woven fabrics, and it would range

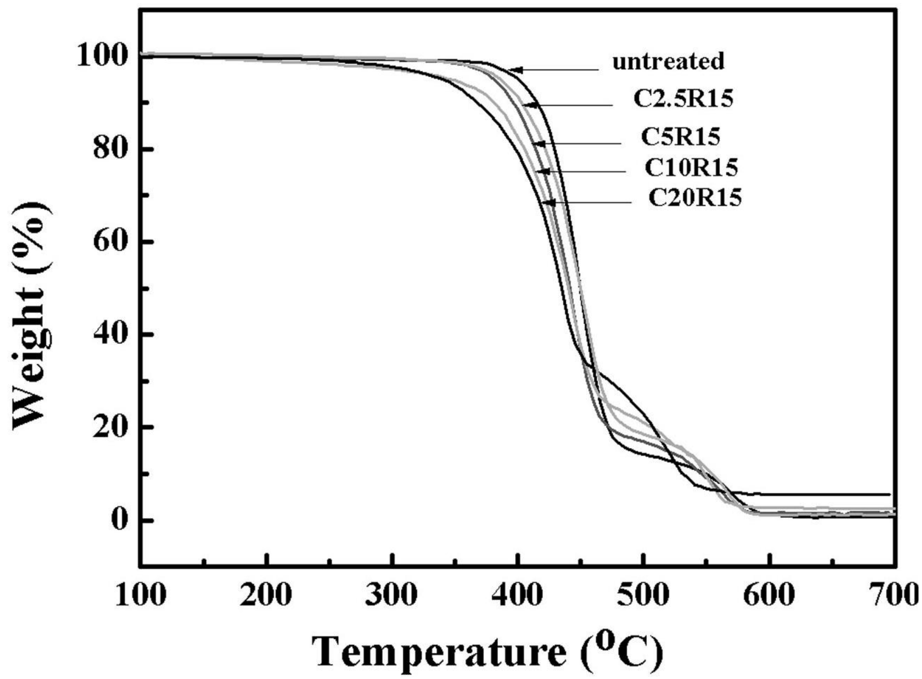

Figure 3. The TGA diagram of processed non-woven fabric by different condition C2.5R15 means activated bamboo charcoal concentration is 2.5 g/L, resin concentration is 15%; C5R15 means activated bamboo charcoal concentration is 5 g/L; C10R15 means activated bamboo charcoal concentration is 10 g/L; C20R15 means activated bamboo charcoal concentration is 20 g/L.

from 453.4 to 480.8°C. The residue of resin on the surface of the PET fabrics could be responsible for the second stage of thermal degradation. The amount of resin residue at 700°C would reach to 1.31 and 5.66% for the concentrations of the activated bamboo charcoal being 2.5 and 20 g/L, respectively. As expected, the more the concentration of the activated bamboo charcoal would bring into higher amount of resin residue.

Influence of bamboo activated charcoal and resin concentration on the softness of non-woven fabrics

The softness of non-woven fabrics is associated with comfort and the "feeling" of non-woven products. The softness of non-woven fabrics treated with different concentrations of bamboo activated charcoal and resin was assessed using an experimental machine. Table 2 shows the analytical results for softness. The treated non-woven fabrics are less soft than the untreated fabrics. The difference in softness of fabrics treated with three different resin concentrations was insignificant.

As bamboo activated charcoal is only attached to the fabric surface, adding bamboo activated charcoal in different concentrations affect merely the softness of the treated non-woven fabrics. Comparing the overhang length of the treated non-woven with the untreated non-woven in different resin concentrations, the results show that overhang lengths would increase from 7.8 to 17.2% and 0 to 8.7% along the machine direction and across direction of non-woven, respectively. Consequently, the resin concentration would exhibit almost no effect on the overhang length of the treated non-woven fabrics, although the resin concentration is up to 15%.

Influence of bamboo activated charcoal and resin concentration on the surface abrasion of non-woven fabrics

Non-woven fabrics treated with different concentrations of bamboo activated charcoal and resin, were tested for surface abrasion using an experimental machine. Figure 4 shows the abrasion test results. Compared with untreated non-woven fabrics, the treated non-woven fabrics would possess higher abrasion resistance. Comparing non-woven fabrics treated with three different concentrations of resin, the surface abrasion would increase as resin concentration increases, reaching the highest surface abrasion up to 3000 cycles when resin concentration is 15%. Therefore, non-woven fabrics possess excellent abrasion resistant properties. Figure 4 shows that the abrasion assessment of untreated non-woven is 303 cycles and the abrasion assessment of

Table 2. Overhang length effect of processed non-woven fabric by different condition.

Resin concentration (%)	BC concentration (g/L)	Overhang length (cm)	
		MD	CD
5	2.5	7.3	7.5
	5	6.9	7.4
	10	7.2	7.2
	20	7.1	7.2
10	2.5	7.3	7.2
	5	7.2	7.1
	10	7.4	7.3
	20	7.0	7.1
15	2.5	7.2	7.3
	5	7.0	7.1
	10	7.3	7.2
	20	7.5	7.4

Untreated non-woven fabric: MD is 6.4 cm, CD is 6.9 cm.

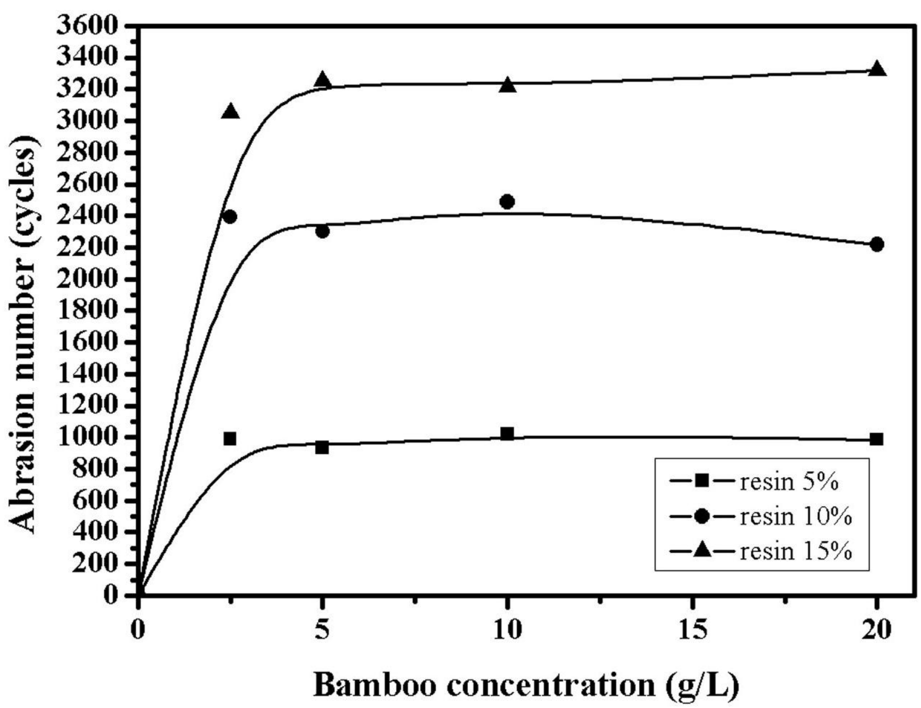

Figure 4. Abrasion number of processed non-woven fabric by different condition. Abrasion number of untreated non-woven fabric is 303 cycles.

treated non-woven is 991 cycles in the resin concentration of 5% under the constant bamboo active chocolate concentration of 2.5 g/L. Moreover, the abrasion assessment of treated non-woven is 2392 cycles in the resin concentration of 10% and the abrasion assessment of treated non-woven is 3049 cycles in the resin concentration of 15%. Based on the abrasion assessment, we can conclude that comparison with untreated non-woven the increasing times of the treated non-woven are 2.27, 6.89 and 9.06, implying that the more resin dosage would inhibit the better resistant of abrasion tenacity. By the way, Figure 4 also shows that the effect of bamboo concentration on the resistant of abrasion tenacity is insignificant.

Table 3. Tear strength of processed non-woven fabric by different condition.

Resin concentration (%)	BC concentration (g/L)	Tear strength (gf)	
		MD	CD
5	2.5	1253	1568
	5	1227	1617
	10	1407	1522
	20	1360	1836
10	2.5	1010	1510
	5	1040	1280
	10	947	1407
	20	1113	1347
15	2.5	933	947
	5	733	913
	10	720	933
	20	980	893

Table 4. Tensile Strength of processed non-woven fabric by different condition

Resin concentration (%)	BC concentration (g/L)	Tensile Strength (kgf/mm^2)	
		MD	CD
5	2.5	11.9	14.2
	5	11.8	13.8
	10	11.8	14.7
	20	11.0	14.4
10	2.5	12.5	16.7
	5	12.0	18.5
	10	12.1	17.9
	20	12.3	18.8
15	2.5	13.7	18.2
	5	12.8	18.9
	10	12.4	18.9
	20	12.6	19.4

Untreated non-woven fabric: MD is 9.1 kgf/mm^2, CD is 10.8 kgf/mm^2.

Influence of bamboo activated charcoal and resin concentration on the tear strength of non-woven fabrics

Non-woven fabric treated using different concentrations of bamboo activated charcoal and resin was tested for tear strength using an experimental machine. Table 3 presents the tear strength test results. The tear strength of treated non-woven fabrics is poorer than that of the untreated fabrics. Tear strength would decrease as resin concentration increases. At higher concentration of resin the non-woven fabrics would become hard and brittle, so the fabrics are easily torn. Adding bamboo activated charcoal did not significantly affect the tear strength of non-woven fabrics. Comparing the tear strength of the treated non-woven with the untreated non-woven in different resin concentrations, the tear strength would decrease from 16.3 to 57.1% and 22.6 to 62.4% along the machine direction and across direction of non-woven, respectively. Accordingly, we can conclude that the higher resin concentration would apparently result in the less tear strength and the variation of tear strength is tiny on the across direction and the machine directions of non-woven.

Influence of bamboo activated charcoal and resin concentration on the tensile strength of non-woven fabrics

Non-woven fabrics were treated using different concentrations of bamboo activated charcoal and resin, and they were subjected to tensile strength testing using an experimental machine. Table 4 indicates treated

Table 5. The ability to heat retention of processed non-woven fabric on different bamboo concentration.

Resin concentration (%)	BC concentration (g/L)	Surface temperature (°C)		≥T (°C)
		a*	b*	
5	2.5	24.00	28.28	4.28
	5	24.53	30.92	6.39
	10	24.17	32.12	7.95
	20	24.57	32.83	8.26

a* is the temperature of before radiation. b* is the temperature of after radiation.

non-woven fabrics have stronger tensile strength than that of the untreated fabrics. Comparing the treated fabrics in different concentrations of resin, the tensile strength would increase as the resin concentration increases. The tensile strength of latitudinal non-woven fabrics is likely stronger than the longitudinal fabrics due to the properties of PET non-woven fabrics. Bamboo activated charcoal did not significantly affect the tensile strength of non-woven fabrics. Comparing the tensile strength of the treated non-woven in different resin concentrations with that of the untreated non-woven, the tensile strength value would increase from 20.9 to 50.5% and 27.8 to 79.6% on the machine direction and across direction of non-woven, respectively. Accordingly, we can conclude that the higher resin concentration would result in the larger tensile strength, and that the increase in the tensile strength along the cross direction of non-woven is more than that of the non-woven along the machine direction.

Influence of bamboo activated charcoal concentration on the ability of non-woven fabrics to heat retention

Bamboo activated charcoal was bound on the surface of non-woven fabrics using resin to impart an ability of releasing far infrared ray to the fabrics and to enhance the heat retention ability of the fabrics. These properties will improve the blood circulation of the human body and enhance metabolism, thereby helping to prevent diseases (Zhang et al., 2008; Lin et al., 2008). Based on the experimental results shown in Table 5, before exposure to a halogen lamp, the surface temperature of fabrics was between 24.0 to 24.57°C, and after exposure, the temperatures of fabrics treated with 2.5, 5, 10 and 20 g/L bamboo activated charcoal were 28.28, 30.92, 32.12 and 32.83°C, respectively. Therefore, the surface temperature would increase as the bamboo activated charcoal concentration increases.

Table 5 presents the temperature difference on the fabric surface before and after exposure to a halogen lamp. The temperature difference is between 4.28 to 8.26°C. When the concentration of bamboo activated charcoal increases, the retained temperature increases. Therefore, the ability in heat retention of the treated non-woven products would increase as the bamboo activated charcoal concentration increases.

Influence of bamboo activated charcoal concentration on release of negative ions from non-woven fabrics

It is well known that the negative ions could exist in the atmosphere. Textiles that can produce negative ions were first developed in Japan. Negative ions released from bamboo activated charcoal can refresh the air and induce human cells to activate the immune system. Based on results shown in Figure 5, the concentration of negative ions released from non-woven fabrics treated with 0, 2.5, 5, 10 and 20 g/L bamboo activated charcoal were 120, 420, 450, 540 and 630 ions/cm^3, respectively, ranging from 420 to 630 ions/cm^3. Therefore, a high concentration of bamboo activated charcoal would increase the concentration of negative ions released. With bamboo concentration of 2.5 g/L, the concentration of negative ions released would increase about 0.91 times as compared with that of the untreated one. Moreover, with bamboo concentration of 20 g/L, the concentration of negative ions released would increase 1.86 times. We can find that the adding of the bamboo active charcoal could possess the function of negative ions releasing.

Influence of bamboo activated charcoal concentration on the deodorization function of non-woven fabrics

Once activated, bamboo activated charcoal contains a large number of benefits, which have an excellent ability to adsorb and decompose ozone, and can also adsorb, decompose and deodorize against benzene, phenol, ammonia, methanol, and sulfide, all of which are harmful chemicals (Wang et al., 2007; Lin et al., 2007). Bamboo activated charcoal was attached to the surface of non-woven fabrics using resin to achieve the deodorization effects. Based on the results shown in Table 6, the remaining NH_3 gas concentration after one hour test would decrease as the bamboo activated charcoal concentration increases. Thus, the deodorization rate of the treated non-woven products could be promoted as bamboo activated charcoal concentration increases with

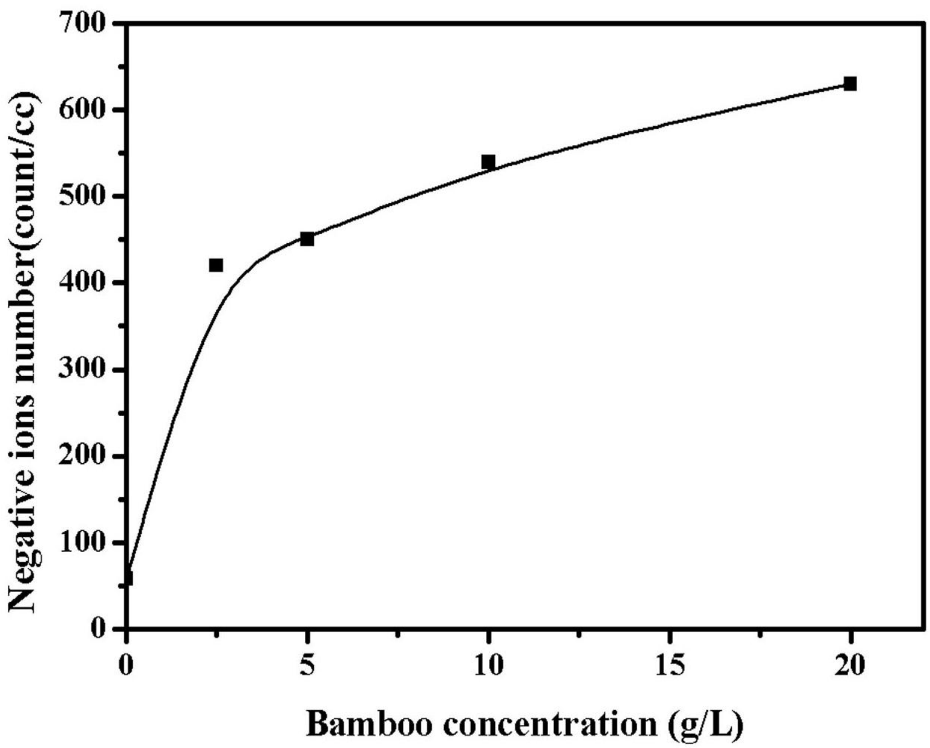

Figure 5. Negative ions number of processed non-woven fabric on different bamboo concentration.

Table 6. Anti-odor ability of processed non-woven fabric on different bamboo concentration.

Resin concentration (%)	BC concentration (g/L)	0 h	1 h	NH_3 exhaustion (%)
		NH_3 Initial conc. (ppm)	NH_3 Retain conc. (ppm)	
5	0	100	88	12
	2.5	100	15	85
	5	100	13	87
	10	100	13	87
	20	100	8	92

an increment of deodorization rate ranging from 85 to 92%, indicating good deodorization effect.

Conclusion

Multi-functional bamboo activated charcoal was bound on the PET non-woven fabrics. The heat retention ability of the treated non-woven products indicates that the surface temperature on treated non-woven fabrics would increase roughly by 4.28 to 8.26°C, suggesting that the heat retention ability could be improved as the concentration of bamboo activated charcoal increases. The negative ions releasing of the treated non-woven products would be improved as the concentration of bamboo activated charcoal increases. The deodorization of ammonia gas for the PET non-woven demonstrate that there is an increasing tendency for deodorization of ammonia gas and an increasing in bamboo activated charcoal concentration. Abrasion strength and tensile strength of the treated PET non-woven would increase in tensile strength but decrease in tear strength as the resin concentration increases. And the variation of decrease in the MD and CD would range from 16.3 to 62.4%. Resin concentration affects the fabric softness merely. Bamboo activated charcoal does not obviously affect the tensile strength, tear strength, abrasion strength and softness of the treated non-woven products. The surface of untreated non-woven fabrics is smooth and well ordered; however, one can observe that the bamboo activated charcoal would be covered with resin on the fiber surface of the treated fabrics.

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