The Effect of Modifier on Properties of Bamboo Powder/High-Density Polyethylene Composites

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Abstract

The focus of this study was to observe the properties of bamboo plastic composites modified with a self-made modifier, 18 acyl-dopamine (0, 0.25, 0.50, 0.75, 1.00, and 1.25 weight percent [wt%] based on the dry weight of bamboo powder). The effects of the modifier were demonstrated by measures of mechanical properties, water absorption, thermal stability, and scanning electron microscopy (SEM). The results revealed that 18 acyl-dopamine could be used as an effective modifier of bamboo powder/high-density polyethylene composites. When the modifier was increased, the toughness of the composite deteriorated, and the strength and rigidity improved. This indicated that when the dosage became higher, the compatibilization became stronger, and the toughening effect became worse. Based on the experimental data, a small dosage modifier acted as a toughening agent; as the dosage increased to 1.0 wt%, the compatibility began to appear. The modifier reacted with the hydroxyl groups on the surface of the bamboo powder, which caused the bamboo powder to absorb less water, so the thickness expansion rate was lowest at 1.25 wt%. The pyrolysis peak of bamboo powder and plastic showed a tendency to be close to each other, indicating that the interface was improving. Based on the equation of Flynn-Wall-Ozawa, as the dosage of the modifier increased from 0.50 to 1.25 wt%, the apparent activation energy also increased. The SEM analysis showed the binding between bamboo powder and the plastic matrix was strongest when the modifier dosage was 1.25 wt%.

Bamboo plastic composites have many advantages. Compared with traditional glass fiber and mineral filler reinforced material, bamboo is an environmentally friendly natural filler for composites with lower density and cost, used in many fields (Burgueno et al. 2005, Tan et al. 2011, Yu et al. 2014, Ou et al. 2015). It provides a good solution for China because of China's shortage of timber resources, increased waste plastic pollution, and bamboo resources advantage. Interface compatibility is the main problem that restricts the development of bamboo plastic composites (Xie et al. 2010, Wang et al. 2014). Thus, improving the interfacial bonding strength of bamboo plastic composites is one of the issues that should be addressed for improving high-value use of bamboo. The solutions to this problem include modifying plant fiber and plastic, as well as adding interface compatibilizers. Traditional methods of fiber surface modification include physical modification and biological modification, among others. Li et al. (2008) used trichloroacetic acid as an activator, with the aid of acetic anhydride to achieve chemical modification. Lee et al. (2009) used alkali-treated bamboo fiber, treated with silane to improve the compound material mechanics. Polymer chain modification of thermoplastics to add polar functional groups is typically accomplished through chemical reactions (Krishnan and Narayan 1992). Previous researchers have tried to graft maleic anhydride's thermoplastic plastic and wood pulp fiber composites, and the resulting composite material had good mechanical properties. The structure of the compatibilizer, which contained hydrophilic and hydrophobic functional groups, allowed for interactions with both the polymer and the bamboo powder and improved the

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interfacial properties. Du et al. (2014) used maleic anhydride-grafted polyethylene as an additive to prepare bamboo plastic composites.

Previous research has found dopamine to be the main component of adhesion proteins for shellfish, which can form polydopamine with oxygen and can adhere to any solid material surface (Waite 2008). Catechol groups of polydopamine have chemical versatility, which can bond through hydrogen bonding, hydroquinone charge transfer complex chelating, forming the super adhesive ability of polydopamine (Gu et al. 2013). Using the structure of the dopamine to solve the incompatible problem of composites, bionics research has developed groups with double functions of ''dopamine,'' which have obtained advancements in multifunctional coatings, medical uses, and other applications (Waite 2008, Gu et al. 2013). Catechins in the dopamine group form hydrogen bonds with the fiber surface, and the alkyl chains can interact with the polymer matrix, which can enhance the interfacial bonding of composites (Ji et al. 2016). Recently, polydopamine was used to improve halloysite nanotubes' matrix dispersion and interface interaction between poly(lactic acid), improving the mechanical properties and interfacial compatibility of the composites (Luo et al. 2016). Yuan et al. (2017) introduced polydopamine to fabric with aramid/polytetrafluoroethylene hybrid and found that tensile and agglutination intensity of amino functional fabric composites was improved compared with the untreated group. Also, the dopamine in the polymer matrix and the interfacial compatibility of carbon nanometer tubes, such as packing, was also found to have a promoting effect (Wan et al. 2015).

Polydopamine has been used to modify crystallization behavior of the ramie fiber/polymer composite interface (Zhou et al. 2014). A literature search has shown that dopamine self-polymerization promotes the compatibility of bamboo powder with plastics. Also, the physical property indexes of composites using various plastic substrates significantly increased with dopamine (Hong et al. 2017). The use of dopamine directly for reinforced polymer composites of natural fibers is less reported.

This study is based on the ideas of increasing the compatibility and modification of bionic ''dopamine,'' through chemically synthesizing the marine mussel's super adhesive key functional element ''Dopa'' derivative from 18 acyl-dopamine, as a self-made modifier. Modified bamboo powder was extrusion blended with high-density polyethylene (HDPE), and composite panels were fabricated by hot press molding. The bending strength, elastic modulus, impact strength, water absorption, and thermal stability were evaluated. The effect of apparent activation energy at different temperatures was determined by pyrolysis kinetics, and scanning electron microscopy (SEM) was used for evaluating composite sections.

Materials and Methods

Materials

Bamboo powder from moso bamboo residue, 60 mesh, was bought from Lin Brand Wood Powder Co. (Deqing, China). High-density polyethylene (density 0.95 g/cm^3) was bought from Sinopec Group (Beijing, China). The self-made modifier content of 18 acyl-dopamine was 63.24 percent. Distilled water, ethylenediaminetetraacetic acid disodium salt (EDTA-2Na), and ethyl acetate were prepared. The two compounds were analyzed for their purity.

The impregnation method was used to modify the bamboo powder. Five modifier treatment levels were designed to detect the effect of the different dosages of 18 acyl-dopamine on the physical properties of the bamboo plastic composites (Table 1).

Preparation of bamboo plastic composite

We selected 40 mass fractions of bamboo powder in proportion with the mass fraction of 60 HDPE mixed at 180 seconds in a high-speed mixer until the components were evenly dispersed. The material was then placed into a twin-screw extruder. The process parameters are shown in Table 2. After the extrudate was cooled, it was shattered into granules by pulverization. The composite panels were prepared by a hot pressing–cold pressing process in a 270 by 270 by 3-mm mold. The hot pressing parameters were temperature at 160°C, 4 MPa for 9 minutes, while cold pressing was conducted at room temperature, 4 MPa pressure for 5 minutes. Three sets of samples were prepared for each formulation. Samples were taken and tested in accordance with ASTM D618-2008 (ASTM International 2008). Samples were conditioned at 23°C and 50 percent relative humidity for 4 days prior to testing.

Performance testing

The flexural properties were tested in accordance with ASTM D790 (ASTM International 2010a) using a Shimadzu AG-IS (Kyoto, Japan) with a 50 KN load cell and 20 mm/min cross head speed. The size of the test specimens was 84 by 11 by 3 mm, and at least six specimens were tested at each treatment level.

Ten test specimens per formulation, measuring 84 by 11 by 3 mm, were tested for impact strength using the no-gap impact method of ASTM D6110 (ASTM International 2010b) using a KERUI CREE-1002C (Dongguan, China).

The water absorption was determined using ICS 83.120 Q 23 (Standardization Administration of China 2005) with specimens measuring 50 by 50 by 3 mm, which were soaked for 9.5 days. The weight gain was determined at 0.5, 1, 1.5, 2, 3, 4, 5.5, 7.5, and 9.5 days. There were six test specimens per level.

The thermogravimetric analysis was conducted with the method of ASTM E2402 (ASTM International 2011). Five

Table 1.—The designations of the control and different experiment levels.[a]

	Constant factor				Variable factor
No.	Bamboo powder (g)	HDPE (g)	EDTA-2Na (g)	Ethyl acetate (mL)	Self-made modifier (wt %)
Control	96.2	144.3	2.0	200	0
Level 1	96.2	144.3	2.0	200	0.25
Level 2	96.2	144.3	2.0	200	0.50
Level 3	96.2	144.3	2.0	200	0.75
Level 4	96.2	144.3	2.0	200	1.00
Level 5	96.2	144.3	2.0	200	1.25

[a] The mass fraction of 18 acyl-dopamine is a percentage of the quality of bamboo powder. HDPE = high-density polyethylene; EDTA-2Na = Ethylenediaminetetraacetic acid disodium salt; self-made modifier = 18 acyl-dopamine; wt% = weight percent of bamboo powder.

Table 2.—Twin-screw extruder process parameters.

Feed rate (rpm/min)	Revolution rate (rpm/min)	Extruder Temperature (°C)				
		Area 1	Area 2	Area 3	Area 4	Area 5
12	30	160	165	170	165	160

to eight milligrams of composite flour were measured with a nitrogen flow rate at 50 mL/min, a heating rate at 10°C/min, and temperature at room temperature to 810°C. Four specimens were tested per level.

SEM was used to scan the impact section morphology of the bamboo plastic composites. The specimens were coated with a 15-nm-thick platinum film in a vacuum. The vacuum in the SEM chamber is guaranteed at less than 5.5×10^{-5} Pa, and the scanning voltage at 5 to 7 kV.

Results and Discussion

Effect of 18 acyl-dopamine on the mechanical properties of composite

Table 3 shows that, compared with the control, as the dosage of 18 acyl-dopamine increased from 0 to 0.50 weight percent (wt%), the static flexural strength and bending load resistance of bamboo plastic composites showed a decreasing trend. According to the analysis results of variance, the static flexural strength decreased at level 2, and the *P* value was 0.02, which was smaller than α, 0.05. It reached the lowest mean value of 26.38 MPa. As the dosage increased from 0.50 to 1.25 wt%, the rupture strength increased, and the maximum mean value was 27.70 MPa at the dosage of 1.25 wt%, which was lower by 1.7 percent compared with the control. Variance analysis of six levels showed the large difference between the control and the treated samples, with a *P* value of 0.001.

Compared with the control, as the dosage of 18 acyl-dopamine increased from 0 to 1.00 wt%, the elastic modulus of bamboo plastic composites decreased, and the toughness gradually increased. The elastic modulus was 1,697 MPa at level 4, reduced by 10.4 percent compared with the control, with a *P* value of 0.00, smaller than 0.05. As the dosage of 18 acyl-dopamine increased to 1.25 wt%, the elastic modulus rapidly increased, and the brittleness gradually increased. The greatest average elastic modulus was 1,869 MPa at level 5 and was 1.3 percent less than the control. Variance analysis of six levels showed the large difference between the control and the treated samples, with a *P* value of 0.00, smaller than 0.05.

As the dosage of 18 acyl-dopamine increased from 0 to 1.00 wt%, the impact strength and toughness increased. When the dosage increased to 1.00 wt%, the average impact strength was 10.90 KJ m^3, which was greater than the control. The impact strength gradually increased from levels 1 to 4, then decreased at level 5. With the toughness reduced, the even impact strength was 10.31 KJ m^3, lower by 7.2 percent compared with the control, with a *P* value of 0.00, smaller than 0.05. Variance analysis of six levels showed the large difference between the control and the treated samples, with a *P* value of 0.00, smaller than 0.05. When the dosages were between 0 and 0.50 wt%, rupture strength and modulus of elasticity showed a downward trend, while impact strength showed an upward trend. The molecular structure of the 18 acyl-dopamine was mainly composed of a long chain type of polyolefin and, combined with the plastics substrate, which established a pliable interface layer between bamboo powder and the plastics substrate (Fasihi and Mansouri 2016), weakened their interface binding. The molecular motion space was increased, which effectively mitigated the transient impact on the material. However, the bending property of the material was lowered and the impact performance was improved. This function was similar to the plasticizer stearyl acid (Zhu et al. 2013).

Figure 1 shows that when the dosage increased from 0.50 to 1.00 wt%, the static flexure strength and impact strength were improved, but the elastic modulus slightly decreased. It shows that the modifier in this range embodied the effect of compatibilization, promoting the combination of bamboo powder and plastic matrix, ultimately increasing the bending resistance of the material (Biswal et al. 2013). As the modifier dosage increased, its interfacial compatibility began to increase due to the affinity of the dopamine groups of 18 acyl-dopamine to the free polar functional groups of the bamboo powder surface. At the same time, the dopamine benzene ring and hydrocarbon groups are physically entangled with the long-chain olefin functional groups of HDPE, thereby effectively improving the two-phase interface and increasing the strength of the composite (Yeh et al. 2009, Zhu 2013).

The elastic modulus and impact strength of composites showed a downward and an upward trend, respectively. The increasing amplitude of impact strength was higher than the elastic modulus at 6.3 and 3.1 percent, respectively. As the modifier dosage gradually increased, the hydroxyl groups on the surface of the bamboo powder reacted with dopamine, and the remaining octadecylalkyl hydrocarbons remained without any reactive groups, which enhanced the function of its external lubrication on the plastic matrix, so that the bamboo powder units that were grafted with 18 acyl-dopamine had good dispersion in the plastic matrix. The agglomeration phenomenon of bamboo powder was effectively reduced. The stress concentration zone decreased as the agglomeration decreased, so that when the material was

Table 3.—Mechanical properties of bamboo plastic composites with different dosages of 18 acyl-dopamine.[a]

Types		Control	Level 1	Level 2	Level 3	Level 4	Level 5
Rupture strength (MPa)	average	28.17 A	27.34 AB	26.38 C	26.71 C	27.25 BC	27.70 AB
	SD	1.46	1.56	2.07	1.81	1.45	1.13
Elasticity modulus (MPa)	average	1,894 A	1,753 BC	1,752 CD	1,705 CD	1,697 D	1,869 AB
	SD	247	195	206	137	106	198
Impact strength (KJ m^2)	average	9.62 C	9.71 C	10.25 B	10.53 B	10.90 AB	10.31 A
	SD	0.57	0.39	0.60	0.65	0.82	0.76

[a] Different letters indicate significant difference between groups.

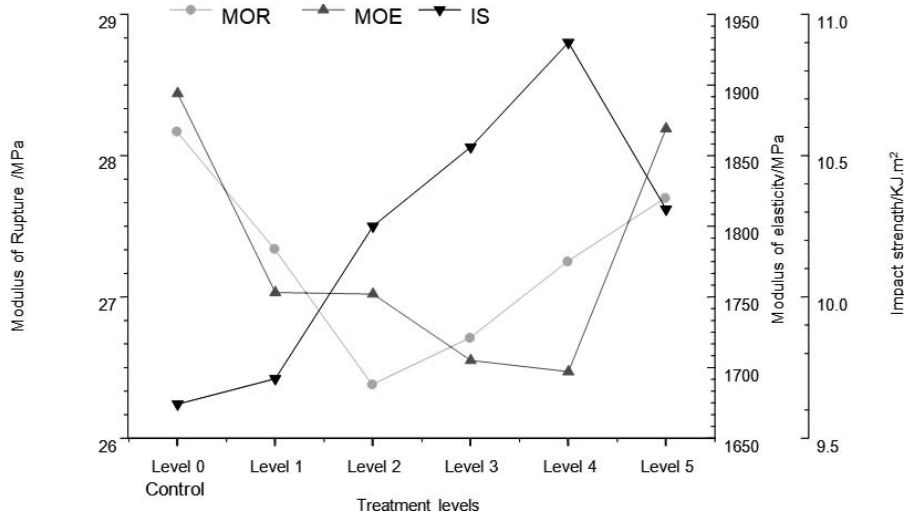

Figure 1.—Mechanical mean values of bamboo plastics composites processed by different dosages of 18 acyl-dopamine.

impacted, the polyethylene around the bamboo powder produced silver grain cracking to absorb the deformation work of the material (Chen et al. 2016). This phenomenon decreased the bending modulus.

At 1.25 wt% modifier content, the impact performance of the composite appeared significantly reduced, which could be due to the chemical bonding of the dopamine-hydroxyl group with the hydroxyl group of bamboo fiber. The bond reduced the polarity of the bamboo fiber surface and improved the compatibility between the two phases of bamboo and plastic, thus improving the tensile properties. If the amount of modifier, the block of HDPE, and the rigid molecules of bamboo fiber are increased, the hydroxyl group involved in the reaction does not increase. Meanwhile, with the increase of compatibility agent, it is easy to form a weak interface between the two phases, which is not conducive to the tensile properties of the material (Lee et al. 2007).

The above results show that with the modifier increasing to a certain dosage, the toughness of the composite deteriorates, and the strength and rigidity improve. This indicates that when the dosage becomes higher, the compatibilization becomes stronger, and the toughening effect becomes worse. Based on the experimental data, we found that a small dosage of the modifier acts as a toughening agent and increases the compatibility more (Li 2015).

Effect of 18 acyl-dopamine on the water absorption of the composite

The changes of water absorption rate and thickness expansion rate after water absorption are shown in Figure 2. The surface hydroxyl of bamboo fiber is easy to combine with water. We know that the thickness expansion rate is caused by bamboo powder, not by plastic. The high water absorption rate indicates that the water enters easily and the thickness expansion ratio may be high.

Figure 2a shows that the water absorption rate of the composites modified with 18 acyl-dopamine showed a similar upward trend. The water absorption rate of all dosages are a little lower compared with the control, which indicates that the modifier can improve the water absorption of materials.

Figure 2b shows that modified composites had a lower thickness expansion rate compared with the control group. And with time delay, the thickness expansion rate after water absorption showed an increasing trend. When the dosage of the modifier was 0.25 percent, partial hydroxyl groups on the surface of bamboo powder reacted with dopamine, and the remaining hydroxyl swelled after water absorption. As increasing dosages were added, the bamboo powder hydroxyl group was completely reacted and could not swell after water absorption, so the thickness expansion rate was the lowest at 1.25 wt%.

Effect of 18 acyl-dopamine addition on pyrolysis properties of composites

Table 4 lists the pyrolysis parameters of bamboo plastic composites with different weights of 18 acyl-dopamine. Among them, TiC was the initial thermal degradation temperature, and T_1 and T_2 were the first and second peaks in the differential thermal gravity (DTG) curve of the material. Figure 3 shows that there were two pyrolysis peaks in the bamboo powder (BP)/HDPE composite. The first peak was mainly generated by the degradation of hemicellulose and cellulose, which occurred between 329.1°C and 349.1°C. The second peak was derived from the decomposition of the HDPE matrix, which ranged from 483.5°C to 470.2°C.

The data from 800 carbon residue rate showed a decreasing trend. The TiC, T_1, and T_2 of BP/HDPE composites prepared with different dosages of 18 acyl-dopamine were compared with the control group. TiC increased by 1.40, 2.42, 0.07, 0.70, and 1.32 percent; T_1 increased by 1.25, 6.08, 0.64, 0.58, and 5.07 percent; and T_2 decreased by 0.21, 0.83, 0.34, 0.49, and 0.11 percent. The results showed that the initial thermal stability of the material was improved when heated, and the T_1 change showed that the addition of 18 acyl-dopamine promoted the thermal stability of bamboo powder in the composite (Tang et al. 2017). T_1 change further indicated that this may be because 18 acyl-dopamine increased the interfacial force between bamboo powder and the plastic substrate, which

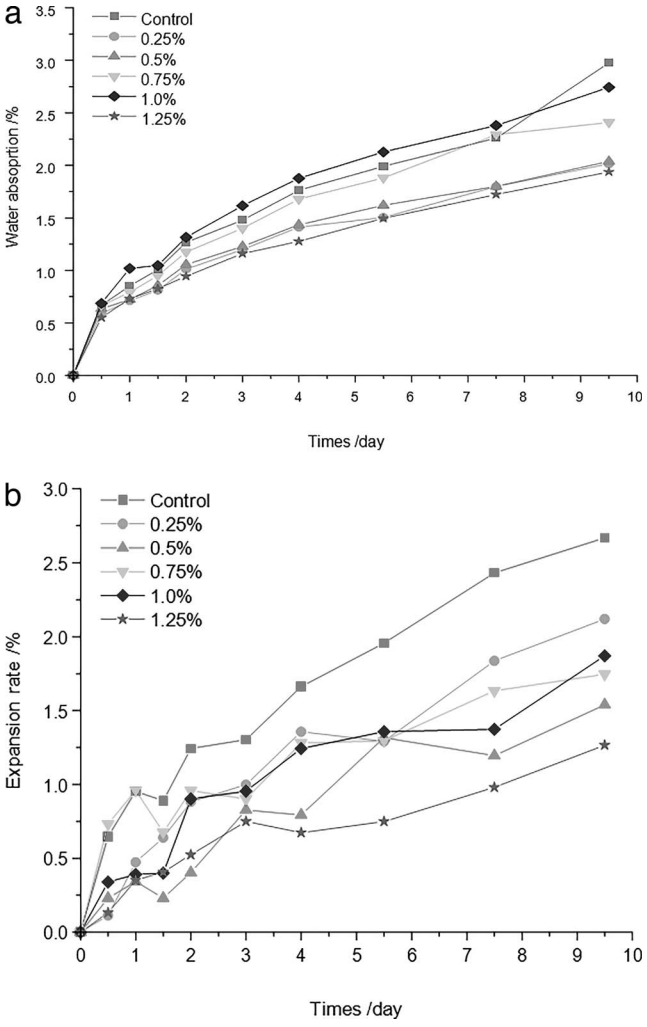

Figure 2.—Water absorption changes of composites with different dosages of 18 acyl-dopamine; (a) the change in water absorption rate, (b) the change in water absorption thickness expansion rate.

restricted the movement of cellulose and hemicellulose molecules, which ultimately improved the thermal stability. As can be seen from T_2 changes, the addition of 18 acyl-dopamine caused a slight decrease in the thermal stability of the plastic matrix of the composite material. This may be because the 18 acyl functional groups of 18 acyl-dopamine played a certain plasticizing role on the plastic, which intensified the molecular movement of the plastic matrix when heated and promoted the thermal decomposition of the plastic matrix at high temperature.

Effect of 18 acyl-dopamine on pyrolysis kinetics of BP/HDPE composites

Previous research has shown that heating rate has a significant impact on the pyrolysis kinetics of bamboo plastic composites, which caused the maximum peak temperature of the DTG curve of the sample to shift to high temperature in the pyrolysis process (Xian et al. 2018).

Previous reports confirm that the change in the pyrolysis curve of wood–plastic composites under different heating rates is mainly due to the difference in the pyrolysis process and the opportunity of secondary pyrolysis with different heating rates, which leads to the difference in temperature at each decomposition stage (Xu et al. 2010).

In this study, the Flynn-Wall-Ozawa method was used to calculate the pyrolysis kinetic parameters of the composite at different heating rates in order to obtain the changes in apparent activation energy and then quantitatively characterize the interfacial compatibility of the material during the pyrolysis process (Venkatesh et al. 2013, Hesabi et al. 2017).

The equation of Flynn-Wall-Ozawa is as follows (Sajna et al. 2017):

$$\lg\beta = \lg\left[AE_\gamma/Rf(\gamma)\right] - 2.315 - 0.4567E_\gamma/RT$$

where γ is the pyrolysis conversion rate; $f(\gamma)$ is a function related to the conversion rate of the pyrolysis of the reaction; A is a frequency factor (min^{-1}); E_γ is the apparent activation energy; and T is 273 K, thermodynamic absolute temperature. This equation can be understood as a constant function under the same conversion rate at different heating rates. This equation indicates that the function under the same conversion rate is a constant under different heating rates. In short, this equation can be converted into a linear equation of $\lg\beta$ and $1/T$. The apparent activation energy of the material under this conversion rate can be obtained by finding the slope k of the linear equation.

According to previous research, it has been found that under low conversion rate conditions (10%) and high conversion rates (90%) of plant fiber reinforced thermoplastic polymer, the composite material had different reaction mechanisms, which would have a certain impact on the experimental results and analysis. This study selected the conversion range from 20 to 80 percent. Also, a different heating rate β (10°C/min, 20°C/min, 30°C/min, 40°C/min) was selected based on the equation of Flynn-Wall-Ozawa (Huang et al. 2012), under the same conversion rate γ, and the apparent activation energy slopes were obtained.

Figure 4 shows the linear relationship between the apparent activation energy of bamboo plastic composites at different heating speeds and the same conversion rate. Table 5 shows the pyrolysis kinetic parameters of bamboo

Table 4.—The pyrolysis parameters of bamboo plastic composites with different weights of 18 acyl-dopamine.

Types[a]	HDPE[b]	Control	Level 1	Level 2	Level 3	Level 4	Level 5
TiC (°C)	421.6	228.3	234.0	236.8	229.5	231.38	234.3
T_1 (°C)	—	329.1	333.2	349.1	331.2	331.0	345.8
T_2 (°C)	483.5	470.7	469.7	466.8	469.1	473.0	470.2
800 Carbon residue rate (%)	0.1	10.0	9.0	7.7	8.9	9.5	7.9

[a] TiC was the initial thermal decomposition temperature; T_1 and T_2 were the first and second peaks on the differential thermal gravity curve of the material, respectively.

[b] HDPE = high-density polyethylene.

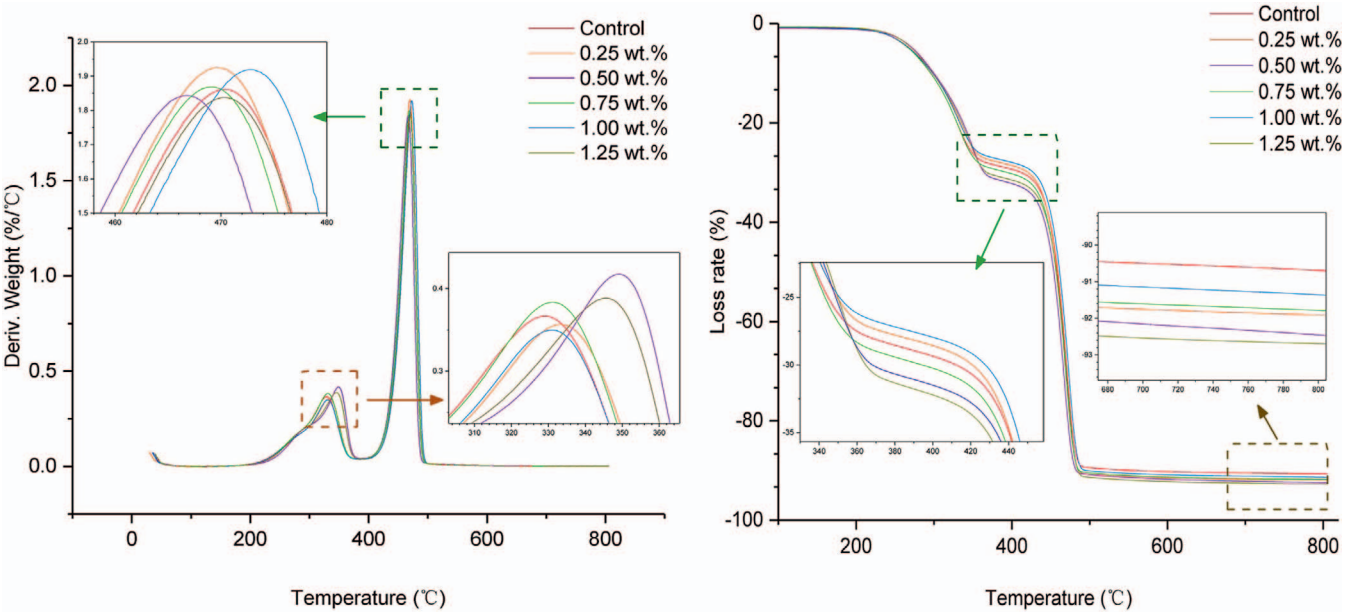

Figure 3.—Thermal decomposition curves of bamboo plastic composites with different dosages of 18 acyl-dopamine.

plastic composites. According to Figure 4 and Table 5, when the conversion rate before and after modification is 40 to 80 percent, and the reciprocal temperature is 1.2 to 1.4, the slope difference of the fitting line is relatively low. This result was similar to the research of Wang (2011). When the conversion rate of composite material is 30 percent, the main component of pyrolysis is bamboo. Figure 4 shows that the pyrolysis temperature of bamboo components at different heating rates all move toward low temperature. Also, with the change of heating rate, the slope of linear change of pyrolysis temperature was somewhat different, and there was a hysteresis phenomenon of heat transfer with the increase of temperature. This finding may be due to the uneven distribution of 18 acyl-dopamine in microscopic conditions. Also, when the amount of 18 acyl-dopamine exceeds 1.25 wt%, the thermal degradation temperature of bamboo powder components is lower than the control group while the linear change range of other conversion rates is not large. This indicates that 18 acyl-dopamine increased the thermal conductivity of the material, making the decomposition lower at different heating rates of bamboo powder.

Previous studies have shown that the thermal stability of bamboo and plastic composites increased with the improvement of interface compatibility (Avella et al. 2010). Table 5 shows that with the increase of 18 acyl-dopamine, the apparent activation energy of the composite material first decreased and then increased, which is consistent with the changing trend of the material's static mechanical properties and dynamic mechanical properties. When the dosage of 18 acyl-dopamine is 0.25 wt%, the average apparent activation energy in the pyrolysis process of the composite decreases, which may be because a small amount of 18 acyl-dopamine mainly plays a toughening role, weakening the interface bonding between the composites and making the pyrolysis performance of the material worse (Biswal et al. 2013). With increasing dosage from 0.50 to 1.25 wt%, the average apparent activation energy of the material increases, indicating that 18 acyl-dopamine plays a compatibilizer role in the composites.

Table 5.—Pyrolysis kinetic parameters of bamboo plastic composites with different dosages of 18 acyl-dopamine.

Level[a]	R^2	Average apparent activation energy (KJ/mol)
Control	0.9843	196.97 ± 24.00
0.25 wt%	0.9898	128.84 ± 13.62
0.50 wt%	0.9898	207.61 ± 59.08
0.75 wt%	0.9573	204.55 ± 32.85
1.00 wt%	0.9725	200.25 ± 50.94
1.25 wt%	0.9950	223.31 ± 27.05

[a] wt% = weight percent of bamboo powder.

SEM of BP/HDPE composites

Figure 5 shows SEM images of the impact section of the composites when the dosages of 18 acyl-dopamine were 0, 0.25, 0.75, and 1.25 wt%. The surface of the control group was rough, and the dispersibility of bamboo powder was inadequate. The serious agglomeration of bamboo powder is evident. There was an obvious gap while bamboo powder pulled out. The interface compatibility was poor, and the plastic substrate was not able to cover the bamboo fiber bundle.

Figure 5 shows that as the dosage of 18 acyl-dopamine increased to 0.25 wt%, the dispersibility of bamboo powder did not improve. However, the surface of the bamboo powder was coated with a thin wax layer, which may be caused by grafting of the 18 acyl-dopamine onto the surface of the bamboo powder (Song et al. 2015). When the dosage increased to 0.75 wt%, the interface of the material was improved. The 18 acyl-dopamine caused molecules to react with each other to form a block, blocking the gap between composites gradually, and the interface fragility increased. The bamboo fiber bundles were broken at the interface of the material after being impacted. This breakage also made it easier for them to move in two phases when they melted

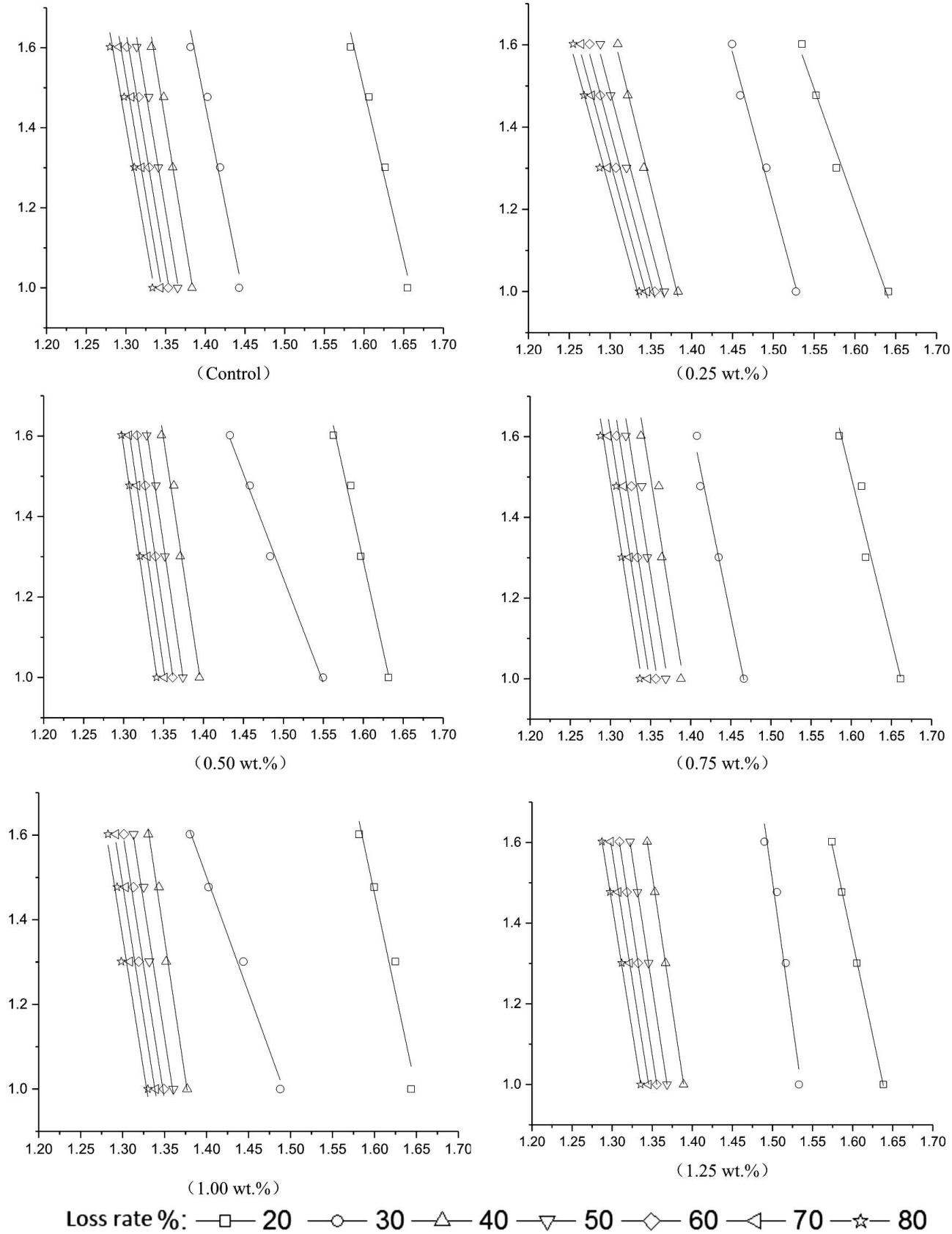

Figure 4.—The evaluation activation energy of bamboo plastic composites by Flynn-Wall-Ozawa method.

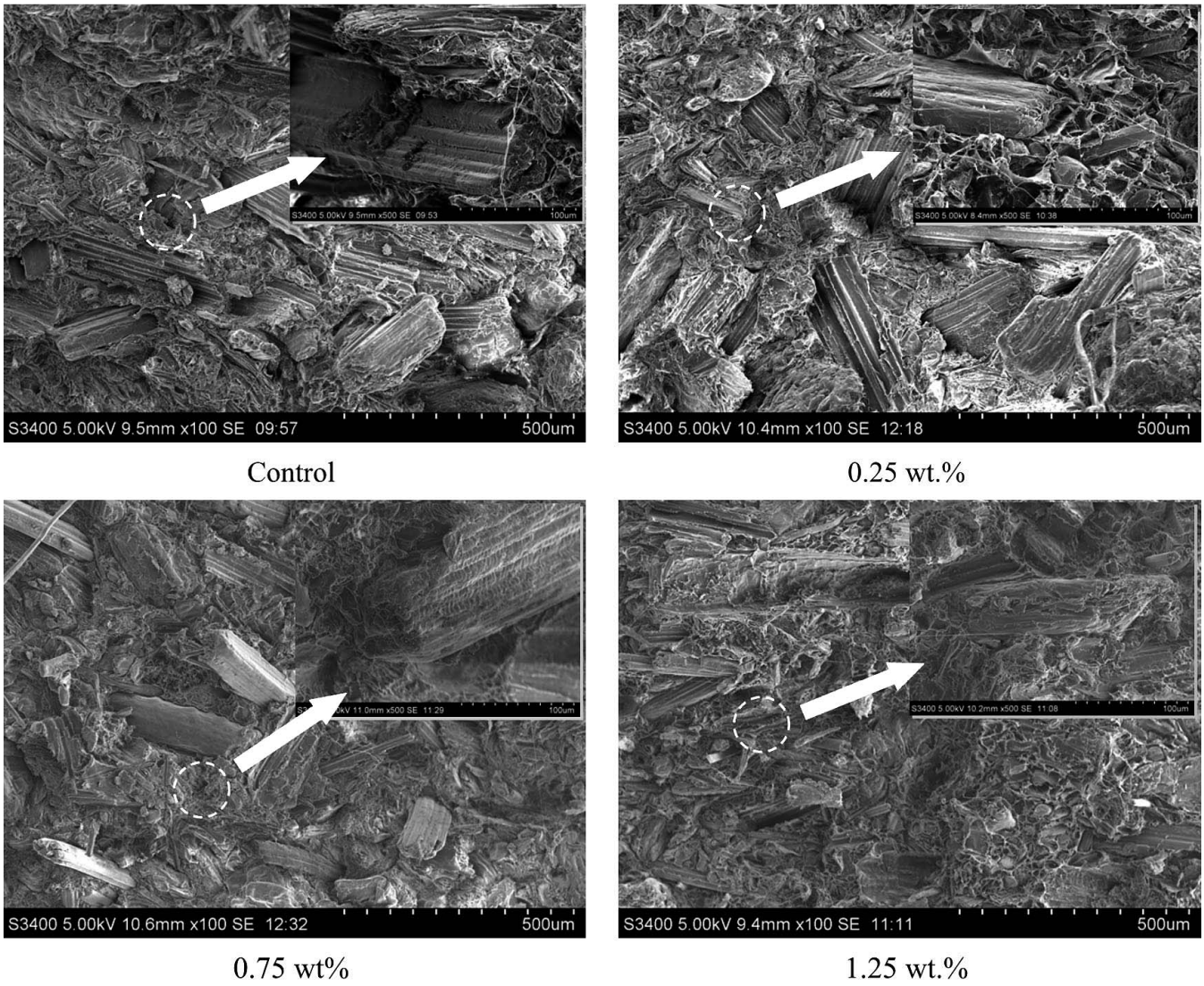

Figure 5.—Scanning electron microscopy of impact section of bamboo powder/high-density polyethylene composites with different dosages of 18 acyl-dopamine.

and blended and improved the bonding between the bamboo powder and plastic (Wu et al. 2011).

The dispersion of the bamboo powder was greatly improved at 1.25 wt% compared with the control, and the surface of the bamboo powder was well coated with the plastic matrix. The interfacial bond was strongest at this level, which was consistent with the results of apparent activation energy analysis.

Conclusions

The 18 acyl-dopamine could be used as an effective modifier of BP/HDPE composites. As the modifier increased, the toughness of the composite deteriorated, and the strength and rigidity improved. This indicates that when the dosage became higher, the compatibilization became stronger, and the toughening effect became worse. Based on the experimental data, we found that a small dosage modifier acted as a toughening agent and increased the compatibility. The modifier reacted with the hydroxyl groups on the surface of the bamboo powder. When the hydroxyl groups on the surface of bamboo powder reacted, the bamboo powder absorbed less water, so the thickness expansion rate was lowest at 1.25 wt%. The pyrolysis peaks of bamboo powder and plastic showed a tendency to be close to each other, indicating that the interface was getting better. Based on the equation of Flynn-Wall-Ozawa, as the dosage of modifier increased from 0.50 to 1.25 wt%, the apparent activation energy also increased. The SEM analysis showed the binding between bamboo powder and plastic matrix was strongest when the modifier dosage was 1.25 wt%.

Acknowledgments

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