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높은 치수 안정성과 고온변형온도를 지니는 PP 개질화를 위한 Talcum Powder와 대나무 숯의 시너지 효과 활용

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Utilization of the Synergistic Effect of Talcum Powder and Bamboo Charcoal to Modify PP with Higher Dimensional Stability and Hot Deformation Temperature

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Abstract: In order to enhance the dimensional stability and hot deformation temperature of PP composites, talcum powder (Talc) and bamboo charcoal (BC) were used as functional filler of PP composites, and a series of Talc/BC/PP composites were prepared. Characteristics, post-moulding shrinkage, hot deformation temperature and mechanical properties of the composites were investigated. The results showed that the surface of BC contains many pores and gaps, and the pores and gaps in the structure of BC were filled by PP (filled-BC) when BC added in PP, and BC filled the gaps between Talc and PP. The BC and Talc for improving dimensional stability and hot deformation temperature of PP have the synergistic effect. The PP composites have the best comprehensive mechanical properties when the addition amount of BC and Talc was 6%.

Keywords: bamboo charcoal, dimensional stability, hot deformation temperature, synergistic effect, comprehensive mechanical properties.

Introduction

Polyolefins are the most widely used and versatile commodity polymers, and their properties vary from plastic to elastomer, such as polypropylene (PP), polyethylene, and polyoxyethylene.[1-4] PP is one of the eminent polyolefins with good chemical and mechanical properties, they are used in a wide range of applications ranging from packaging to lightweight engineering plastics for automobile, electrical and electronics, construction, medical, equipment, and facilities industries.[5-11] However, the dimensional stability, hot deformation temperature, and impact resistance of PP are poor, which limits the use of PP. Therefore, researchers often add inorganic particles to improve the dimensional stability, hot deformation temperature and other properties of PP.[12-21]

Talcum powder (Talc) is a kind of inorganic filler with low price and abundant resources, which can improve the molding and shrinkage properties and thermal stability of plastics.[22-24] Weon *et al.*[25] found that PP/Talc composite material has better tensile modulus, damping characteristics, and higher crystallization temperature than PP. Lubomir *et al.*[26] found that the strength of the composite material was greatest when the amount of nano-Talc added was 20%, the toughness and impact strength of the material were improved. Duquesne *et al.*[27] applied Talc to PP composite materials, which improved the thermal stability of the material, but the flame resistance of the material was reduced. Bamboo charcoal (BC) can be produced from the widespread fast-growing speed and short growth period moso bamboo plants in China. The bamboo and bamboo residues can be transformed to BC at a high temperature under nitrogen atmosphere, which is a mature technology used in China.[28,29] At present, BC is a good reinforcement material for all types of polymers.[30,31] BC has countless small holes lengthwise and crosswise. A good deal

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of holes in BC might be able to produce stronger interface between filler and polymer matrix, because polymer chains could get into these holes when the polymer has good liquidity.[29] Up to now, no published reports are available regarding the synergistic effect of BC and Talc in PP.

Because BC contains a lot of pores and gaps in its structure and PP have good liquidity, so incorporation of BC with PP would lead to better interfacial adhesion between matrix and filler. The objective of this paper was to investigate the synergistic effect of BC and Talc on mechanical properties, hot deformation temperature and dimensional stability of Talc/BC/PP composites prepared by melt-compounding via the twin-screw extruder.

Experimental

Materials. The bamboo charcoal (BC, <5 μm, the effective substance content was ≥99%) was purchased from Shunfa Craft Production Factory (Shenzhen, China). Polypropylene (PP BJ-750) was purchased from Hanwha Total (Korea). The Talcum powder (Talc, <13 μm, the silica content was 60%) was supplied by Dongguan xinshuo new material technology co. LTD.

Preparation of Samples. Formulations of the mixtures and abbreviations used for the respective composites were illustrated in Table 1. The preparation processes of Talc/PP composites, BC/PP composites and Talc/BC/PP composites were schematically shown in Figure 1. The mixtures were premixed before being fed into the first zone of the extruder. Talc/PP composites, BC/PP composites and Talc/BC/PP composites pellets were prepared by using a twin screw extruder (SHJ-20 with average screw diameter of 20 mm and average L/D ratio of 40), with a temperature profile of 175/180/185/190/185/185/185 ℃ and a rotating speed of 120 rpm, and then the extruded strands were passed through a trough and pelletize. The pellets were injected into ISO standard specimens by using an injection molding machine (HMT OENKEY) at 200 ℃.

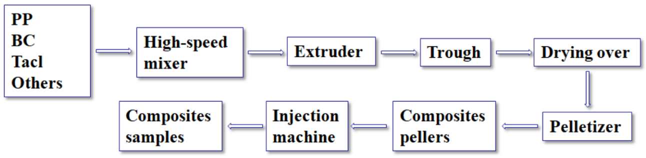

Figure 1. Schematic illustration of preparation processes of Talc/PP, Talc/BC/PP, and BC/PP composites.

Characterization. Scanning electronic microscope (SEM) was performed on JSM-6330F scanning electron microscope with an accelerating voltage of 20.0 kV; the fracture surfaces of samples were coated with a thin layer of gold before analysis.

Dimensional Stability. The dimensional stability of the materials are expressed by the post-moulding shrinkage. The post-moulding shrinkage test was conducted as ISO standards 294-4: 2019. The tests were made in quintuplicate and the results were reported as average.

Hot Deformation Temperature. The hot deformation temperature of the materials is expressed by temperature of deflection under load. The temperature of deflection under load test was conducted as ISO standards 75-1: 2013. The tests were made in quintuplicate and the results were reported as average.

Mechanical Properties. The tensile and flexural tests were carried out by using a universal testing machine (LLOYD LR100K) according to ISO standards 527-1 and ISO standards 178, respectively. The notched Izod impact strengths were conducted following ISO standards 8256 with impact type test machine (ZBC-50). Five samples of each category were tested and their average values were reported.

Results and Discussion

SEM Analysis. Figure 2 illustrated the SEM images of BC, BC/PP composites, Talc/PP composites and Talc/BC/PP-3 composites. It clearly showed that the surface of BC (Figure 2(a)) contains many pores and gaps, and the pores and gaps in

Table 1. Formulations of the Mixtures and Abbreviations for Respective Composites

Materials	Formula (%)						
	Talc/PP	Talc/BC/PP-1	Talc/BC/PP-2	Talc/BC/PP-3	Talc/BC/PP-4	Talc/BC/PP-5	BC/PP
PP BJ-750	82	82	82	82	82	82	82
Talc	12	10	8	6	4	2	—
BC	—	2	4	6	8	10	12
Others	6	6	6	6	6	6	6

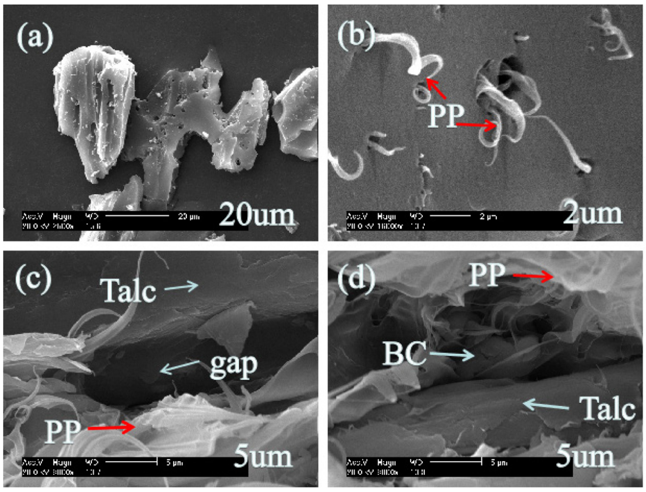

Figure 2. SEM images: (a) BC; (b) the fracture surface of BC/PP composites; (c) the fracture surface of Talc/PP composites; (d) the fracture surface of Talc/BC/PP-3 composites.

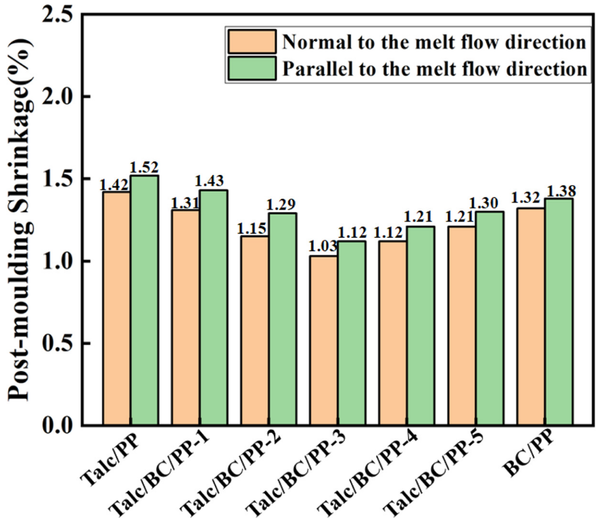

Figure 3. The post-moulding shrinkage of Talc/PP, Talc/BC/PP, and BC/PP composites.

structure of BC were filled by PP (Figure 2(b)) when BC added into PP, which might create better mechanical interlocking between BC and PP. The high magnification image of Talc/PP composites and Talc/BC/PP-3 composites was shown in Figure 2(c) and Figure 2(d). As seen, gaps between Talc and PP can be clearly seen in Talc/PP composites (Figure 2(c)), which suggested that the interaction between Talc and PP was very weak, resulting in less interfacial adhesion. On the other hand, the image of Talc/BC/PP-3 (Figure 2(d)) showed that Talc seemed to be sticky with PP, which let Talc/BC/PP-3 composites have better Talc-matrix interfacial adhesion in its structure. The result might be because the gaps between Talc and PP was filled by BC, which was covered by PP. The morphology results supported the effects on dimensional stability, hot deformation temperature and mechanical properties of Talc/BC/PP composites, which would be discussed below.

Dimensional Stability. Dimensional stability is an important property index of thermoplastic polymers, which expressed by moulding shrinkage, post-moulding shrinkage and total shrinkage, especially post-moulding shrinkage. Figure 3 showed the percentages of the post-moulding shrinkage (normal and parallel) of Talc/PP, BC/PP, Talc/BC/PP composites. After addition of BC, the post-moulding shrinkage parallel to the melt flow direction and the post-moulding shrinkage normal to the flow direction of composites are decreased at first, and then increased. When the addition of Talc and BC was 6%, the post-moulding shrinkage of composites was lowest. The result might be because the size of BC was smaller than Talc, and the pores and gaps in structure of BC were filled by PP, so the filled-BC filled the gaps between Talc and PP, resulting in strong Talc-matrix interface, which was accordant with the results of SEM. And when the amount of talcum powder is sufficient, Talc can block BC from moving, which restricted motion of polymer chains, the post-moulding shrinkage was decreased. Nevertheless, the ability of Talc to hinder BC movement was weakened when the amount of Talc was small, which constrains the movement of polymer chains, the post-moulding shrinkage was increased. Results show that the post-moulding shrinkage of PP composites was smaller with added BC and Talc than separate added the same amount of BC or Talc, which means the BC and Talc for improving dimensional stability of PP has the synergistic effect.

Hot Deformation Temperature. When measuring hot deformation temperature the standard test specimen is subjected to a constant load, the temperature is raised at a uniform rate, and the temperature at which the standard deflection, corresponding to the specified in flexural strain, is measured. Figure 4 showed the effect of BC content on the hot deformation temperature of Talc/BC/PP composites. The hot deformation temperature of composites increased at first, and then decreased. The result was attributed that BC and Talc can restrict motion of polymer chains, and the Talc with flake structure can well prevent the movement of filled-BC when the content exceeds 6%, so the deformation speed of standard spline becomes slower and the hot deformation temperature increases under the action of constant pressure, however, the effect of Talc in blocking the movement of filled-BC becomes worse when the content of BC exceeds 6% and the content of

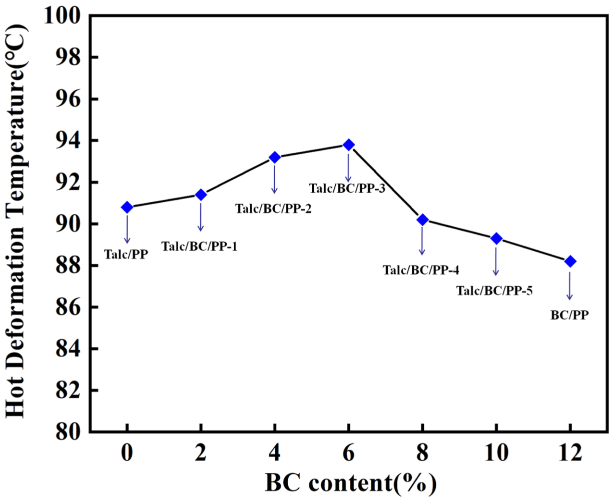

Figure 4. The hot deformation temperature of Talc/PP, Talc/BC/PP, and BC/PP composites.

Talc is lower than 6%, and the possibility of BC and polymer chains moving together increases, therefore, the deformation speed of the standard spline is relatively increased and the hot deformation temperature is relatively reduced under the action of constant pressure. Results show that the hot deformation temperature of PP composites was higher with added BC and Talc than separate added the same amount of BC or Talc, which means the BC and Talc for improving hot deformation temperature of PP have the synergistic effect.

Mechanical Properties. The mechanical properties of Talc/PP composites, BC/PP composites and Talc/BC/PP composites were shown in Table 2. The flexural modulus and flexural strengths of composites increased at first, and then decreased. The result was attributed that BC and Talc decreased in mobility of the polymer chains and decreased the deformation capacity of the matrix in the elastic zone, and Talc is very good at blocking the movement of filled-BC when the content of exceeds 6%, which leads to better restricted motion of polymer chains and the composites became better stiffer, whereas, the effect of Talc on blocking the movement of filled-BC becomes worse when the content of BC exceeds 6% and the content of Talc is lower than 6%, so the stiffer of composites relatively reduced. Unlike the flexural properties of composites, the addition of BC into Talc/PP composites increased the tensile strength and notched Izod impact strengths of composites. The results suggested that the interface adhesion between BC and matrix is better than that between Talc and matrix, and BC can fill the gaps between Talc and PP, so adding BC could improve the Talc-matrix interfacial adhesion, leading to better stress transfer efficiency from the matrix to the filler and improvement of tensile strengths and notched Izod impact strength of the Talc/BC/PP composites. Results show that the PP composites have the best comprehensive mechanical properties when the addition amount of BC and Talc was 6%.

Conclusions

BC and Talc were used as the functional filler for PP composites, and Talc/PP, Talc/BC/PP, BC/PP composites were prepared. The SEM showed that the surface of BC contains many pores and gaps, and the pores and gaps in structure of BC were filled by PP, and BC filled the gaps between Talc and PP, resulting in strong Talc-matrix interface. The post-moulding shrinkage and hot deformation temperature of PP composites were better with added BC and Talc than separately added the same amount of BC or Talc, which means the BC and Talc for improving dimensional stability and hot deformation temperature of PP have the synergistic effect. The flexural modulus and flexural strengths of composites increased at first, and then decreased, indicating Talc with very good at blocking the movement of filled-BC when the content of exceeds 6%. The

Table 2. Mechanical Properties of Talc/PP Composites, BC/PP Composites and Talc/PP/BC Composites

Sample	Flexural modulus (MPa)	Flexural strength (MPa)	Tensile strength (MPa)	Notched Izod impact strengths (KJ/m^2)
Talc/PP	1433.4	24.3	22.3	22.1
Talc/BC/PP-1	1474.1	24.8	22.8	23.2
Talc/BC/PP-2	1523.6	25.6	23.2	24.7
Talc/BC/PP-3	1557.2	25.9	23.7	25.6
Talc/BC/PP-4	1510.4	24.9	24.1	26.7
Talc/BC/PP-5	1414.2	23.8	24.4	27.2
BC/PP	1388.6	22.9	25.2	28.1

interface adhesion between BC and matrix is better than that between Talc and matrix, leading to a better stress transfer efficiency from the matrix to the filler and improvement of tensile strength and notched Izod impact strengths of the PP composites. Results show that the PP composites have the best dimensional stability, hot deformation temperature and comprehensive mechanical properties when the addition amount of BC and Talc was 6%.

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