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Study on the phase structures and toughening mechanism in PP/EPDM/SiO_2 ternary composites

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Abstract

In this paper, EPDM rubber and nano-SiO_2 particles were employed to modify PP simultaneously. Our goal was to control the distribution and dispersion of EPDM and nano-SiO_2 particles in PP matrix by using an appropriate processing method and adjusting the wettability of nano-SiO_2 particles toward PP and EPDM, so as to achieve a simultaneous enhancement of toughness and modulus of PP. With regard to this, two kinds of nano-SiO_2 particles (with hydrophilic or hydrophobic) as well as two processing methods (one-step or two-step) were employed to prepare PP/EPDM/SiO_2 ternary composites. A unique structure with the majority of EPDM particles surrounded by SiO_2 particles was first observed by using hydrophilic SiO_2 and two-step processing method, resulting in a dramatically increase of Izod impact strength as the rubber content in the range of brittle–ductile transition (15–20 wt%). The observation that poor adhesion and poor compatibility between particles and PP matrix could result in a significant increase in Izod impact strength was unusual and needed further investigation. This could be tentatively understood as a consequence of the overlap of the 'stress volume' between EPDM and SiO_2 particles due to the formation of the unique structure. Our work provided a deep understanding of the toughening mechanism and a new way for the preparation of high performance polymer composites.

Keywords: PP/EPDM/nano-SiO_2 ternary composites; Phase structures; Toughening mechanism

1. Introduction

Polymer blending or compounding receives increasingly interest because it is a relatively easy way to obtain new materials with balanced properties. Generally, elastomer is used to improve the toughness but sacrifices the modulus of polymers. Adding inorganic filler can enhance the stiffness but result in a decrease of toughness. To overcome the drawback resulted by only adding elastomer or filler, a lot of work has been done on polymer/elastomer/filler ternary system, where both elastomer and filler were used to enhance the toughness and stiffness simultaneously [1–11]. To achieve the best combination of mechanical properties, the key is to control the dispersion and phase morphology of ternary composites. Concerning the phase morphology containing both elastomer and filler dispersed in polymer matrix, separated microstructure where the elastomer and filler are dispersed in polymer matrix separately, and core–shell microstructure with the filler covered the elastomer, are the two morphologies commonly observed in ternary composites. Argument exists on whether separated dispersion or core–shell microstructure is favor to toughening. Matonis etc. [1,2] concluded that core–shell structure helps increase the toughness, and the thinner the elastomer and the stronger the adhesion between filler and matrix, the higher the toughness of the composites. However, Jancar etc. [11] has shown that the modulus is increased in a condition of separated dispersion while the core–shell microstructure can improve the toughness. The mechanical properties and the morphologies of ternary blends of polycarbonate with a mechacrylated butadiene–styrene impact modifier and various brittle polymers were investigated by Paul et al. They found, very interestingly, that for a better toughness the modifier should be located in the brittle polymer in ternary blend [12]. There are several factors, such as composition, processing conditions, adhesion between filler and elastomer, which may affect the dispersion and microstructure [3–10]. Most work is qualitative on toughening mechanism while the quantitative relationship between morphology and property has not been established yet so far.

Polypropylene (PP) is one of the important commodity polymers. It is widely used in automobile, household appliance and construction industry due to its balanced mechanical

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properties. The application of PP, however, is limited by its brittleness, especially at low temperature, as well as low stiffness at elevated temperature. In order to improve the impact toughness of PP and extend its application range, a lot of extensive and thorough researches on PP toughened with different particles (including both rubber and rigid particles) have been made. Concerning the toughening mechanism, over the years various conceptual models, including crazing, cavitations and shear yielding, have been proposed and worked out [13–21]. One of the most important findings in polymer-toughing is known as the critical matrix ligament thickness (τ_c) theory, which is developed by Wu after an investigation on nylon 6/EPDM blends [22–25] and extended by Qi after an investigation on PP/EPDM blends [26,27]. Only when the matrix ligament thickness (τ) is smaller than τ_c could the shear yielding of matrix ligament exist and does a sharp brittle–ductile transition (B–D transition) of blends occur. More than 10 times' increase in impact strength is observed for PP/EPDM blends at the B–D transition. The key is that the stress fields around individual particle must interfere or overlap with each other and pervade within the matrix to realize a massive shear yielding. A percolation process of stress volume spheres has been successfully used to explain the phenomenon of the B–D transition [28–30].

In this paper, EPDM and nano-SiO_2 particles will be employed to modify PP simultaneously. Our goal is to control the dispersion and distribution of EPDM and nano-SiO_2 particles in PP matrix by using an appropriate processing method and adjusting the wettability of SiO_2 particles toward PP and EPDM, so that the stress fields around EPDM nano-SiO_2 particle can interfere or overlap in PP matrix. In this way, part of EPDM can be replaced by nano-SiO_2 particles for toughing, thus a simultaneous enhancement of toughness and modulus can be achieved. Therefore, two kinds of nano-SiO_2 particles (with hydrophilic or hydrophobic) and two processing methods (one-step or two-step) will be used to prepare PP/EPDM/SiO_2 ternary composites. The relationships between phase structure and impact strength of PP/EPDM/SiO_2 composites are discussed in detail.

2. Experimental

2.1. Materials

The materials used for the preparation of PP/EPDM/SiO_2 composites are listed in Table 1. Polypropylene (PP), EPDM and fumed nano-SiO_2 particles used in our study were commercially available. The hydrophobic nano-SiO_2(A-SiO_2) was treated by coupling agent D4 (octamethyl cyclotetrasiloxane) before used while the hydrophilic nano-SiO_2(B-SiO_2) was received without any pretreatment.

2.2. Sample preparation

Two processing methods were employed to prepare PP/elastomer/filler ternary composites. One was called one-step processing method, in which the elastomer and the filler were directly melt-blended with PP matrix. Another one was called two-step processing method, in which the elastomer and the filler were mixed by means of a two-roll mill at room temperature for 10 min to get masterbatch first, and then the masterbatch was melt blended with pure PP. The blending was conducted in a two-screw extruder at 140–210 °C, and then injection molded in PS40E5ASE (Japan) at 180–210 °C to obtain standard specimen for mechanical properties tests.

2.3. Mechanical tests

2.3.1. Izod impact strength test

The notched Izod impact strength was used to evaluate the toughness of samples. The notched specimens were tested with a VJ-40 impact test machine at room temperature, according to GB/T 1834-1996 standard. Each impact test was repeated at least five times, and the results were averaged.

2.3.2. Yield tensile strength, flexural strength and modulus test

Standard tensile tests were conducted on dumbbell shaped specimens using an AG-10TA tensile testing machine at room temperature. Test speed was kept at 50 mm/min, according to GB/T 1040-92 standard. The flexural strength and flexural modulus were measured using an AG-10TA flexural testing machine with a speed of 2 mm/min according to GB 9341-88 standard. Both of these tests were carried out in five folds.

2.4. Scanning electron microscopy (SEM) experiments

The morphology of the blends was studied by preferential etching of EPDM phase in dimethylbenzene for 2 h. The samples were cryogenically fractured in the direction perpendicular to flow direction in liquid nitrogen before etching. The etched samples were carefully washed for several times by using fresh dimethylbenzene, then alcohol washed for three times. The samples were dried under vacuum at room temperature for 24 h. Then the fractured samples were observed in a JEOL JSM-5900LV SEM instrument, using an

Table 1
Materials

	Materials	Brand	Supplier	Characteristics
	PP	T30 s	Du Shan Zi Petroleum Chemical, China	MFI = 2.64 g/10 min (230 °C, 2.16 kg)
	EPDM	EP35	Japan Synthetic Rubber Co. Ltd	PP content: 43% Mooney viscosity: 83(100 °C) the third monomer: ENB
Fumed nano-SiO_2	Hydrophobic SiO_2 (A-SiO_2)	JT-SQ	Chendu Today chemical Co. Ltd	Particle size: 10–30 nm $S_{(BET)} = 200\ m^2/g$
	Hydrophilic SiO_2 (B-SiO_2)	HL-150	Guangzhou GBS High Tech & Industry Co.	Particle size: 15–20 nm $S_{(BET)} = 150 \pm 10\ m^2/g$

acceleration voltage of 20 kV, which could show the dispersion of elastomer and filler in PP matrix.

3. Results and discussions

To better understand the properties and morphologies of the ternary blends, we begin with PP/A-SiO_2, PP/B-SiO_2 and PP/EPDM binary blends. For both PP/A-SiO_2 and PP/B-SiO_2 binary blends, the Izod impact strength decreases with the addition of SiO_2 particles while the tensile strength, flexural strength and flexural modulus slightly increase with the SiO_2 content as shown in Fig. 1(a)–(d). For PP/EPDM binary blend, as expected, Izod impact strength increases dramatically and a sharp brittle–ductile transition is achieved when rubber content reaches a certain value, companied with a decrease of the tensile strength, flexural strength and flexural modulus, as shown in Fig. 2(a)–(d). It can be seen that a sharp brittle–ductile transition occurs at 15–20 wt% of EPDM content. The toughness of PP/EPDM blend becomes independent of EPDM content when EPDM content is more than 30 wt%. However, when EPDM and nano-SiO_2 particles were used together, a simultaneous increase of the toughness and stiffness in PP/EPDM/SiO_2 ternary composites can be achieved by using an appropriate processing method and adjusting the wettability of SiO_2 particles toward PP and EPDM. Fig. 3 shows the Izod impact strength of different PP/EPDM/SiO_2 composites prepared by two processing methods, respectively. Both hydrophobic SiO_2 particles (A-SiO_2) and hydrophilic SiO_2 particles (B-SiO_2) were used here. By using hydrophobic SiO_2 particles (A-SiO_2), or by using hydrophilic SiO_2 particles (B-SiO_2) but one-step processing method, one observes only a slight increase of Izod impact strength. By using hydrophilic SiO_2 particles (B-SiO_2) and two-step processing method, however, a remarkable increase of Izod impact strength can be seen. A comparison of the stiffness between PP/EPDM/B-SiO_2 (80:20:5) ternary blend and PP/EPDM (70:30) binary blend is list in Table 2. One observes similar Izod impact strength but higher tensile strength, flexural strength and modulus in ternary system.

It is unusual that hydrophilic SiO_2 is better than hydrophobic SiO_2 as a toughening agent based on the wettability of SiO_2 particles toward PP and EPDM. In other words, one in general does not expect hydrophilic filler mixed in hydrophobic polymer to produce materials with good properties. Therefore, SEM experiment was carried out to understand the phase morphology of PP/EPDM/SiO_2

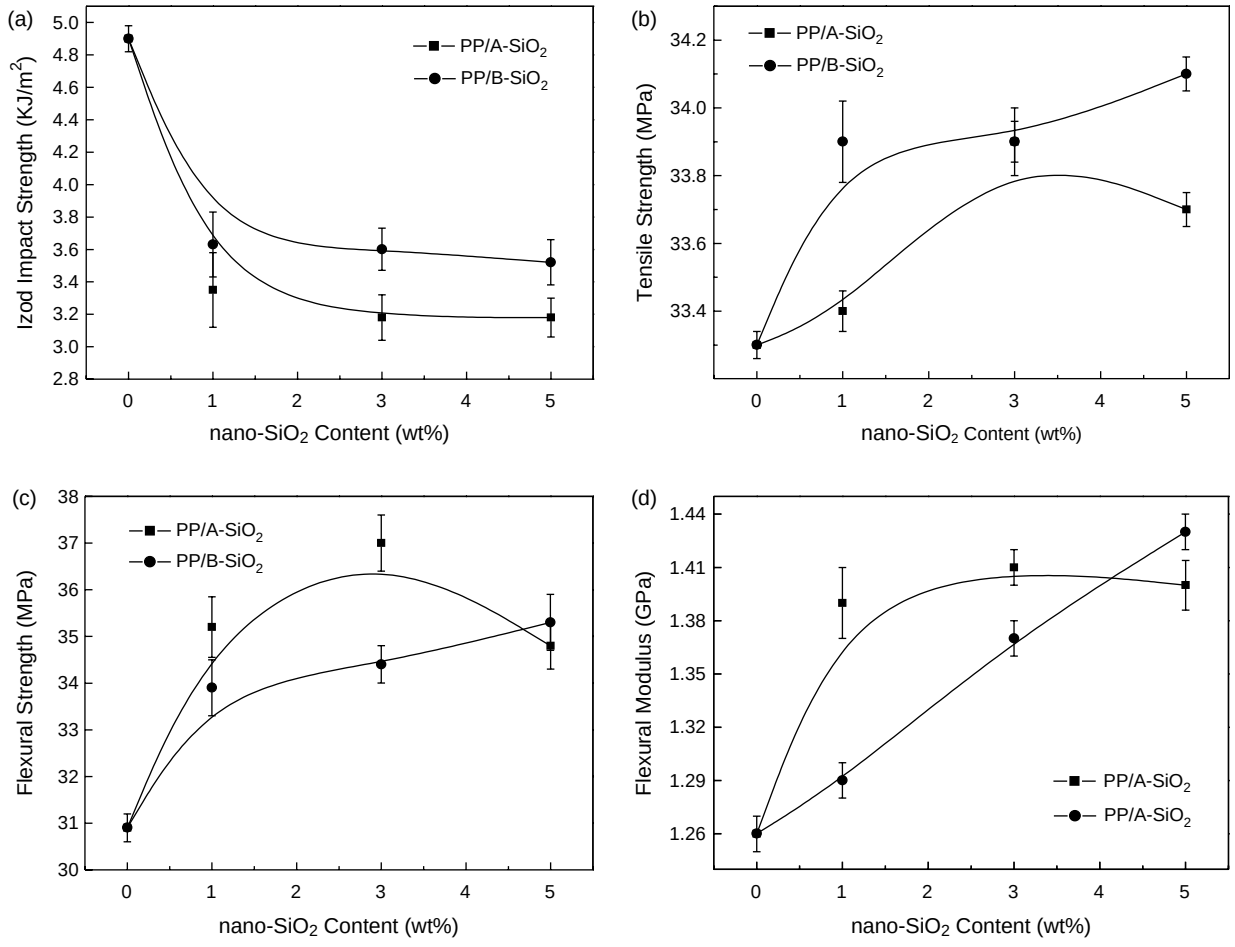


Fig. 1. Mechanical properties of PP/A-SiO_2 and PP/B-SiO_2 binary blends via nano-SiO_2 content (a) Izod impact strength; (b) tensile strength; (c) flexural strength; (d) flexural modulus.

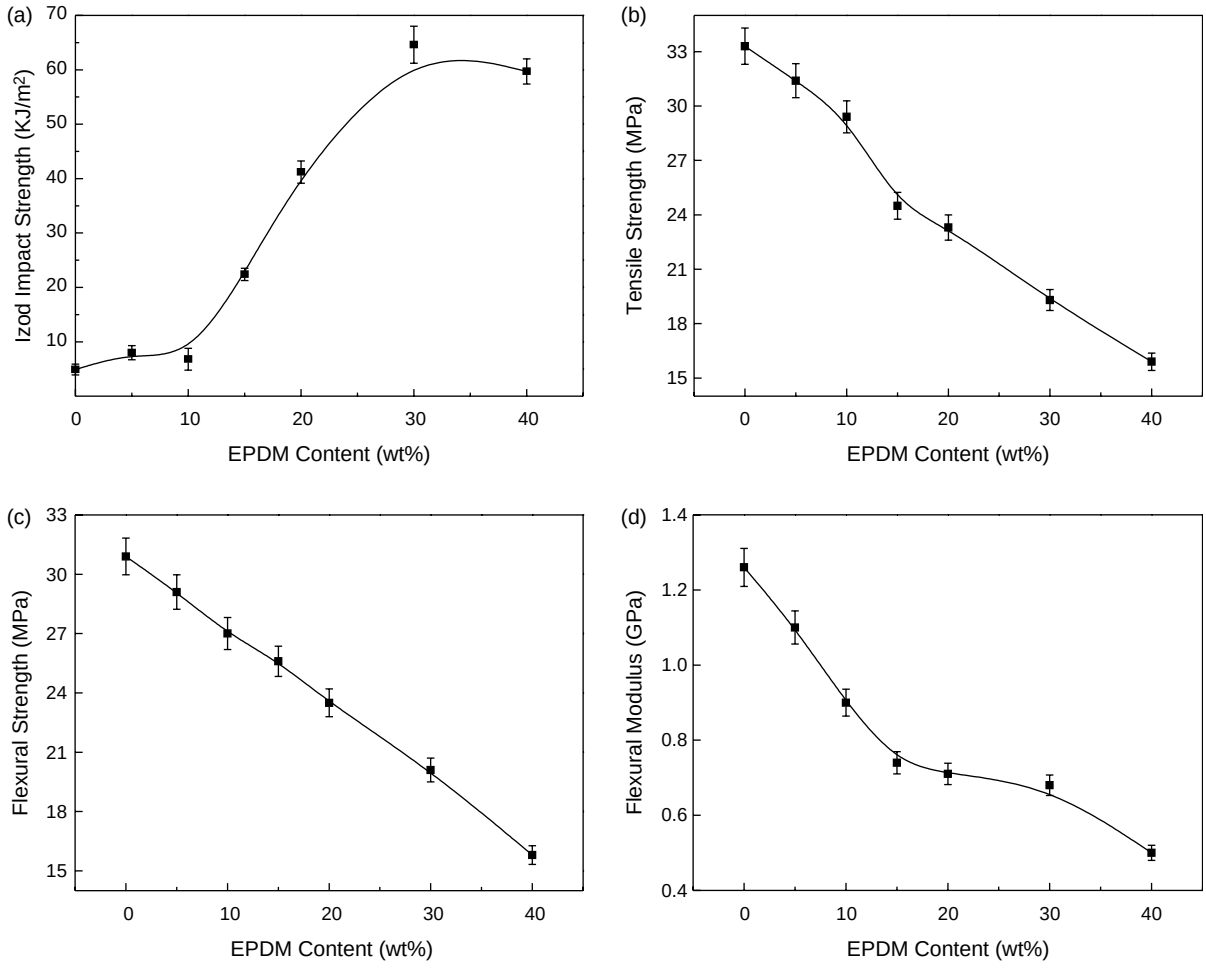


Fig. 2. Mechanical properties of PP/EPDM binary blend via EPDM content (a) Izod impact strength; (b) tensile strength; (c) flexural strength; (d) flexural modulus.

composites. Fig. 4 shows the phase morphology of the samples after selectively etching of EPDM rubber particles. For PP/EPDM/A-SiO_2 composites prepared by one-step processing method and two-step processing method, nearly no difference of phase structure between them can be found. In these two cases, a core–shell structure is most likely formed since few A-SiO_2 particles (bright particles) can be seen in PP matrix (seen in Fig. 4(a) and (b). For PP/EPDM/B-SiO_2 composites prepared by one-step processing method, large aggregates of B-SiO_2 particles with a size of 0.5–1.0 μm exist in PP matrix. As expected, there exists poor adhesion and poor compatibility between particles and PP matrix. Therefore, a separated dispersion structure with large B-SiO_2 aggregates is probably formed (seen in Fig. 4(c)). However, a unique phase structure that a large amount of B-SiO_2 particles agglomerate around EPDM particles (dark holes) and pervade over the PP matrix can be observed in PP/EPDM/B-SiO_2 composites prepared by

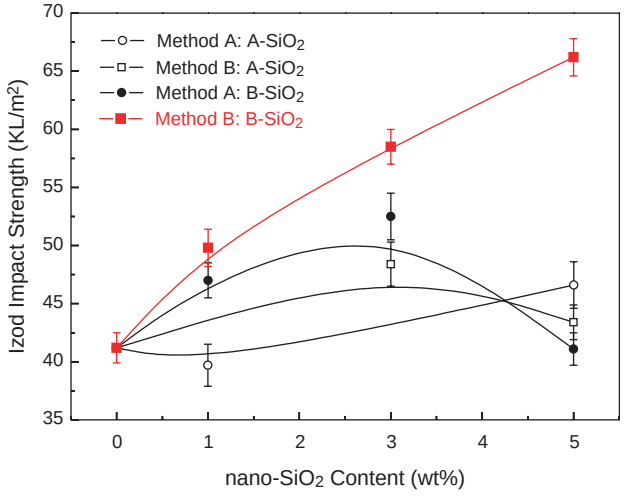


Fig. 3. Izod impact strength versus SiO_2 content for different PP/EPDM/SiO_2 composites prepared by two processing methods, respectively (PP/EPDM = 80:20).

Table 2
The comparison of the mechanical properties between PP/EPDM/B-SiO2 (80:20:5) prepared by two-step processing method and the pure PP/EPDM (70:30)

	Izod impact strength (kJ/m^2)	Tensile strength (MPa)	Flexural strength (MPa)	Flexural modulus (GPa)
PP/EPDM/B-SiO_2 80:20:5	66.2	21.9	23.6	0.83
PP/EPDM 70:30	64.6	19.3	20.1	0.68

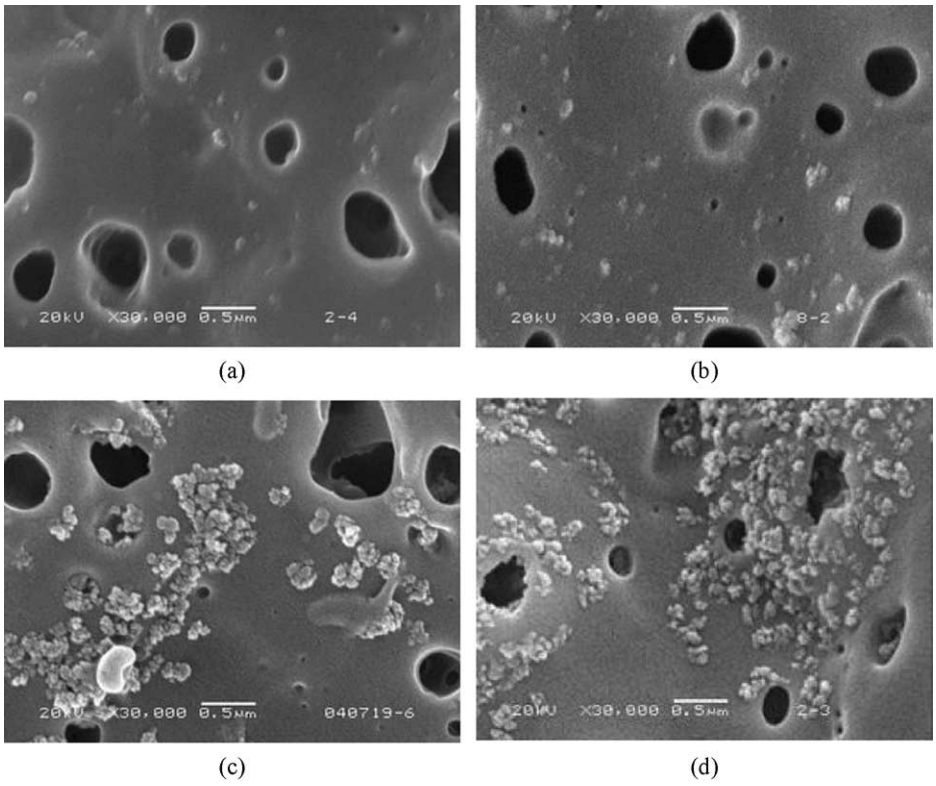


Fig. 4. SEM images of PP/EPDM/nano-SiO_2 (80:20:3) ternary composites (a) one-step, A-SiO_2; (b) two-step, A-SiO_2; (c) one-step, B-SiO_2; (d) two-step, B-SiO_2.

two-step processing method (seen in Fig. 4(d)). Though TEM experiment is needed to get more detailed information of the phase structure of these samples, it is reasonable to believe that it is a unique phase structure that is responsible for the improved Izod impact strength.

In order to provide evidence to the assertion that improved Izod impact strength of PP/EPDM/B-SiO_2 composites prepared by two-step processing method can be related to the formation of this unique phase structure, PP/EPDM/B-SiO_2 composites with three different rubber contents were studied. They were 10 wt% (brittle region), 20 wt% (brittle–ductile transition region) and 30 wt% (ductile region), respectively. The hydrophilic SiO_2 particles (B-SiO_2) content varies from 1 to 5 wt%, and samples were all prepared by two-step processing method. Izod impact strength of PP/EPDM/B-SiO_2 composites as a function of B-SiO_2 content is shown in Fig. 5. It can be seen that, when EPDM content is 20 wt% (brittle–ductile transition region), the Izod impact strength of PP/EPDM/B-SiO_2 composites increases linearly with the increase of B-SiO_2 content. Specifically, the Izod impact strength increases from 41.2 to 66.2 kJ/m^2 as B-SiO_2 content varies from 0 to 5 wt%. In addition, the Izod impact strength of PP/EPDM (80:20) composite with 5 wt% B-SiO_2 particles content (66.2 kJ/m^2) is almost the same as that of the pure PP/EPDM (70:30) composite (64.6 kJ/m^2). The Izod impact strength of PP/EPDM/B-SiO_2 composites, however, increases slightly when EPDM content is 10 wt% (brittle region), and almost keeps constant when EPDM content is 30 wt% (ductile region).

Fig. 6 shows the phase structure of PP/EPDM/B-SiO_2 composites prepared by two-step processing method after selectively etching of EPDM rubber particles. The content of B-SiO_2 particles keeps at 3 wt%. Compared with Fig. 6(a)–(c), it can be found that the average size of EPDM particles (dark holes) almost keeps constant while the average interparticle distance decreases sharply with the increase of EPDM content, varying from 0.37 μm (10 wt% EPDM) to 0.08 μm (30 wt% EPDM). Obviously, the phase structure of PP/EPDM/B-SiO_2

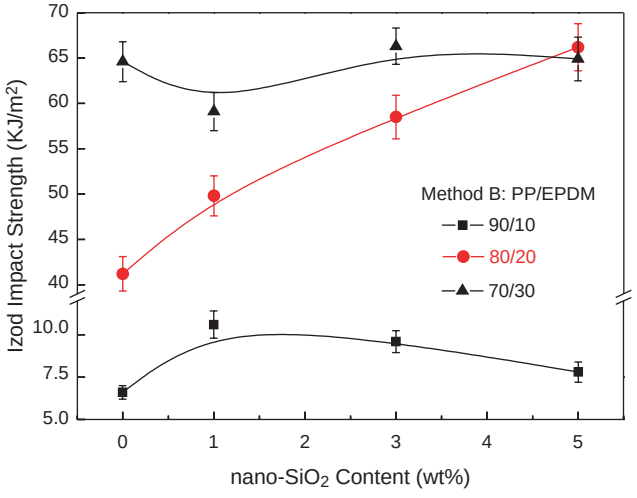


Fig. 5. Variation of Izod impact strength with B-SiO_2 content for various PP/EPDM composites.

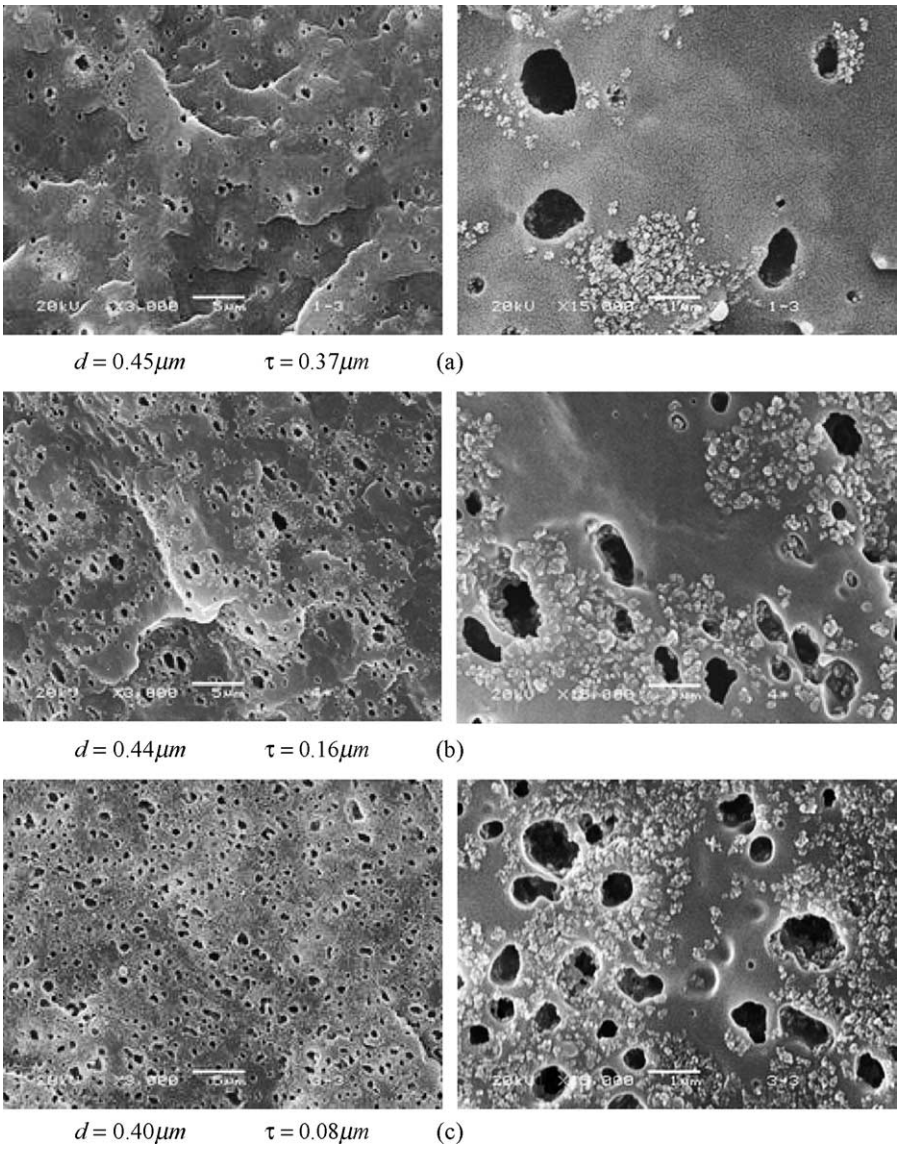


Fig. 6. SEM images of PP/EPDM/B-SiO_2 ternary composites prepared by two-step processing method (a) 90:10:3; (b) 80:20:3; (c) 70:30:3 d, the average rubber particle diameter; τ, the average interparticle distance.

composites varies with the EPDM content. For PP/EPDM/B-SiO_2 (90:10:3) composite, large interparticle distance (also called matrix–ligament thickness) is observed. Besides, some EPDM particles are surrounded by B-SiO_2 particles and a few B-SiO_2 particles can be seen in PP matrix. By adding 20 wt% of EPDM, however, the interparticle distance decreases sharply and a unique phase structure can be observed here, that is, a majority of EPDM particles are surrounded by B-SiO_2 particles, and meanwhile, a network of B-SiO_2 particles is developed and pervaded over the PP matrix. With the further addition of EPDM (30 wt%), not only are all EPDM particles surrounded by B-SiO_2 particles, but also do B-SiO_2 particles occupy the entire PP matrix. This finding is similar with what Paul had noted that for a better toughness the modifier should be located in the brittle polymer in ternary blend [12]. Here the modifier can be considered as EPDM particles and the brittle polymer as B-SiO_2 particles. Now it is logical to ask how this unique phase structure forms via two-step processing method. The equilibrium morphology and the location of the filler within two-phase matrix formed by PP and EPDM, in principle, are determined by interfacial forces of thermodynamic origin and the wettability of SiO_2 particles toward PP and EPDM. In practice, an equilibrium distribution may not be achieved since kinetic issues could play a considerable role in some circumstances [12]. Due to its hydrophilic property, B-SiO_2 particles cannot be wetted by either PP or EPDM. Under the shear force, B-SiO_2 particles will be in this case effectively forced out from high viscosity of EPDM and will eventually agglomerate together in PP matrix just like in the case of one-step processing. Since the agglomerating process will take time, there exists an intermediate state where EPDM particles are surrounded by B-SiO_2 particles. This phase structure can be controlled and frozen in by solidification of PP via adjusting processing conditions including temperature and time.

3.1. Toughening mechansim

3.1.1. Wu's theory

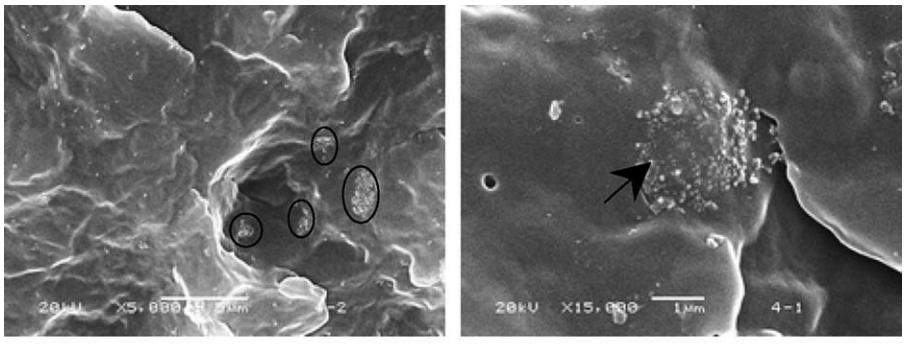
According to the framework of Wu's theory [22–25,28], for polymer/rubber binary composites, a sharp brittle–ductile transition occurred at a critical rubber particle size. And the critical particle size was related to the rubber volume fraction ϕ_r by [23]:

$$\tau_c = d_c[(\pi/6\phi_r)^{1/3} - 1] \quad (1)$$

where d_c was the critical rubber particle diameter, and τ_c the critical surface-to-surface interparticle distance, or the critical matrix–ligament thickness. The value of τ_c was independent of the particle size and rubber volume fraction. τ represented the average surface-to-surface interparticle distance (i.e. the average matrix–ligament thickness) and depended on the rubber volume fraction. If $\tau < \tau_c$, the continuum percolation of stress volume around rubber particles would occur; the matrix yielding would propagate and pervade over the entire matrix, and then the blend would be tough. On the contrary, if $\tau < \tau_c$, the matrix yielding could not propagate, and the blend failed in a brittle manner.

3.1.2. Toughening mechanism

In this study, the hydrophilic SiO_2 particles tend to aggregate around the EPDM particles since hydrophilic SiO_2 particles can be wetted by neither PP nor EPDM. Showing as an example, the dispersion of hydrophilic SiO_2 particles in pure PP matrix is shown in Fig. 7. A poor wetting of the filler within the aggregates is seen (more clearly at high magnification, Fig. 7(b)). These poorly dispersed particles act as voids rather than stiff inclusion, resulting in a decrease of impact strength and only slightly increase of tensile strength, flexural strength and modulus, as can be observed in Fig. 1. For PP/EPDM/B-SiO_2 ternary composites, however, the two-step processing method is convenient to the dispersion of the B-SiO_2 particles and the formation of the unique structure that B-SiO_2 particles agglomerate around EPDM particles. These SiO_2-surrounded EPDM particles can therefore be regarded as a soft core surrounded by rigid SiO_2 particles shell of comparable size, which could increase the effective size of the rubber particles. Then the stress fields around SiO_2 particle can interfere or overlap with those around the EPDM particles when EPDM particles are closely surrounded by SiO_2 particles and a percolation of SiO_2 particles in PP matrix is formed. In this case, the stress fields around SiO_2 particles seem to serve as a bridge between two neighboring rubber particles. Therefore the overlap of the stress volume between EPDM and SiO_2 particles is believed to result in the observed increase of Izod impact strength in PP/EPDM/B-SiO_2 ternary composites with 20 wt% EPDM content. The schematic representation of toughening mechanism for PP/EPDM/SiO_2 composites is shown in Fig. 8. When EPDM content is 10 wt% (brittle region), the interparticle distance is very large. Although the addition of SiO_2 particles, at a certain degree, reduces the matrix–ligament thickness, the interparticle distance is too large to form the continuum percolation of stress volume around the EPDM particles, hence the yielding process cannot propagate and pervade over the PP matrix (seen in Fig. 8(a)). That is why the Izod impact strength of PP/EPDM/B-SiO_2 composites with 10 wt% EPDM content increases slightly with the addition of B-SiO_2 particles. When 20 wt% of EPDM are blended with 80 wt% of PP, the interparticle distance decreases sharply and becomes equivalent to the critical interparticle distance, so that the brittle–ductile transition occurs. After adding SiO_2 particles, EPDM particles are found to be closely surrounded by SiO_2 particles and a percolation of SiO_2 particles over the PP matrix is also observed. Thus the overlap of stress volume between EPDM and SiO_2 particles can be achieved since a large amount of SiO_2 particles agglomerate around EPDM particles and pervade over the PP matrix (seen in Fig. 8(b)). This is of great benefit to the percolation of the yielding process over the PP matrix, thus dramatically enhancing the Izod impact strength of the composite. However, for PP/EPDM binary composite with 30 wt% EPDM content, which is in the regions above the brittle–ductile transition (seen in Fig. 2(a)), the toughness becomes independent of EPDM content because of the mechanical saturation [25]. In other words, there is no need for SiO_2 particles to be the intermediate for the stress fields overlap between two rubber particles (seen in Fig. 8(c)). Therefore, the addition of SiO_2 particles does not have much effect on the Izod impact strength of PP/EPDM composite any longer. So, it is easy to understand the way that the core–shell phase structure obtained in PP/EPDM/A-SiO_2 composites, or



(a) (b)

Fig. 7. SEM images of PP/B-SiO_2 binary blend under low (a) and high (b) magnifications (PP/B-SiO_2 = 97:3).

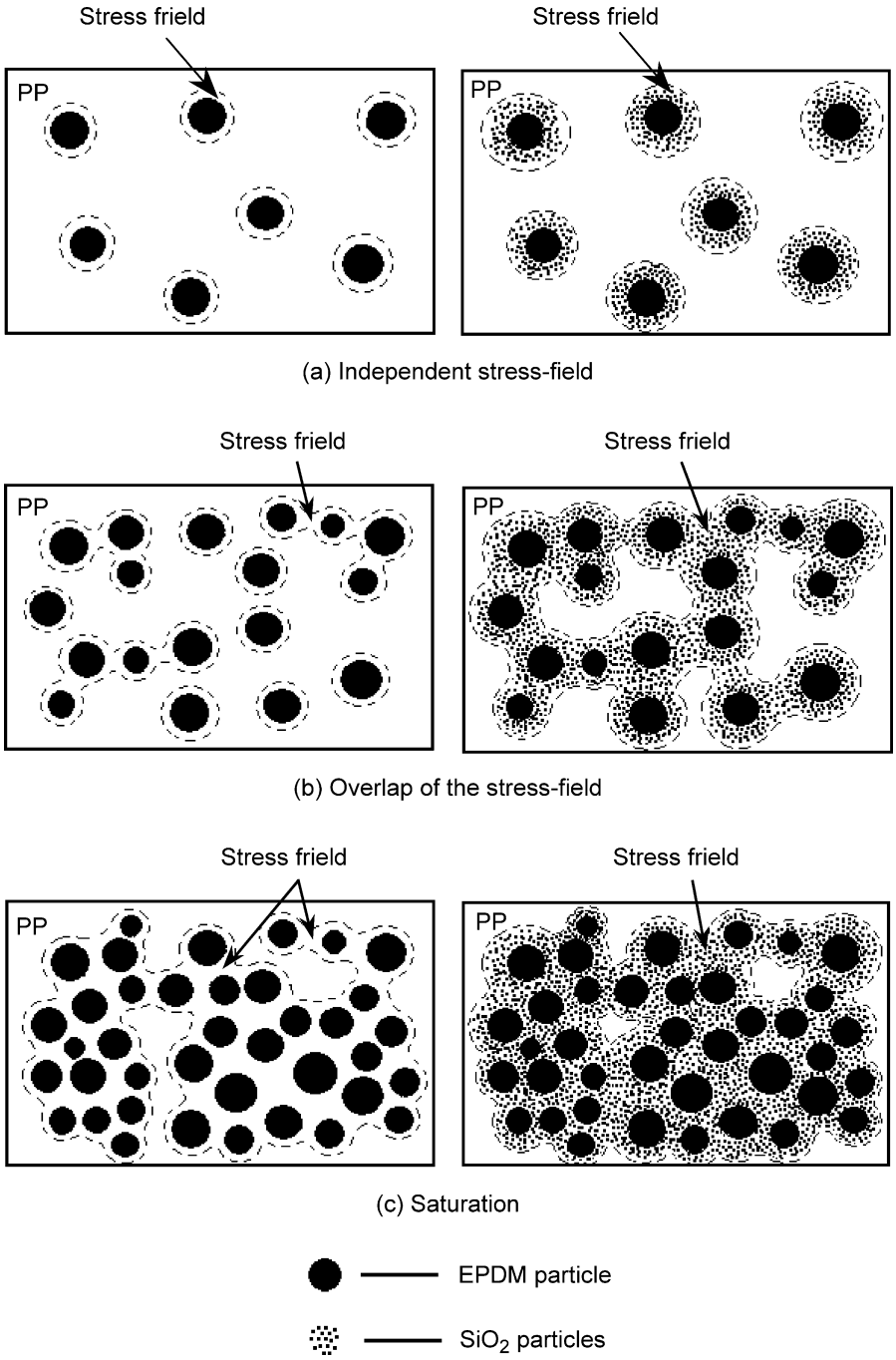


Fig. 8. The schematic representation of toughening mechanism for PP/EPDM/SiO_2 composites (a) $\tau \gg \tau_c$; (b) $\tau \approx \tau_c$; (c) $\tau \ll \tau_c$.

a separated dispersion structure with aggregated SiO_2 particles obtained in PP/EPDM/B-SiO_2 composites prepared by one-step processing method, cannot achieve a remarkable increase of Izod impact strength as shown in Fig. 3. For the core–shell phase structure with SiO_2 particles encapsulated by EPDM, just only a slight increase of the effective volume fraction of EPDM dispersed phases is achieved, which is of little avail to the improvement of Izod impact strength. For the separated dispersion structure with aggregated SiO_2 particles, large SiO_2 aggregates existing in PP matrix act as stress concentrations so that they cannot interact with the stress fields around EPDM particles effectively.

3.1.3. Impact-fractured surface of PP/EPDM/B-SiO_2 ternary composites

To gain more insight in understanding the toughening mechanism mentioned above, it is necessary to investigate the impact-fractured surface of PP/EPDM/B-SiO_2 composites with different EPDM content. Fig. 9 shows the impact-fractured surface of the selected samples, 90:10(90:10:5), 80:20(80:20:5), and 70:30(70:30:5) representing brittle, transition and ductile regions respectively. For PP/EPDM (90:10) binary composite and PP/EPDM/B-SiO_2 (90:10:5) ternary composite, the low Izod impact strengths (<10 kJ/m^2) of them are clearly reflected by their impact-fracture surfaces.

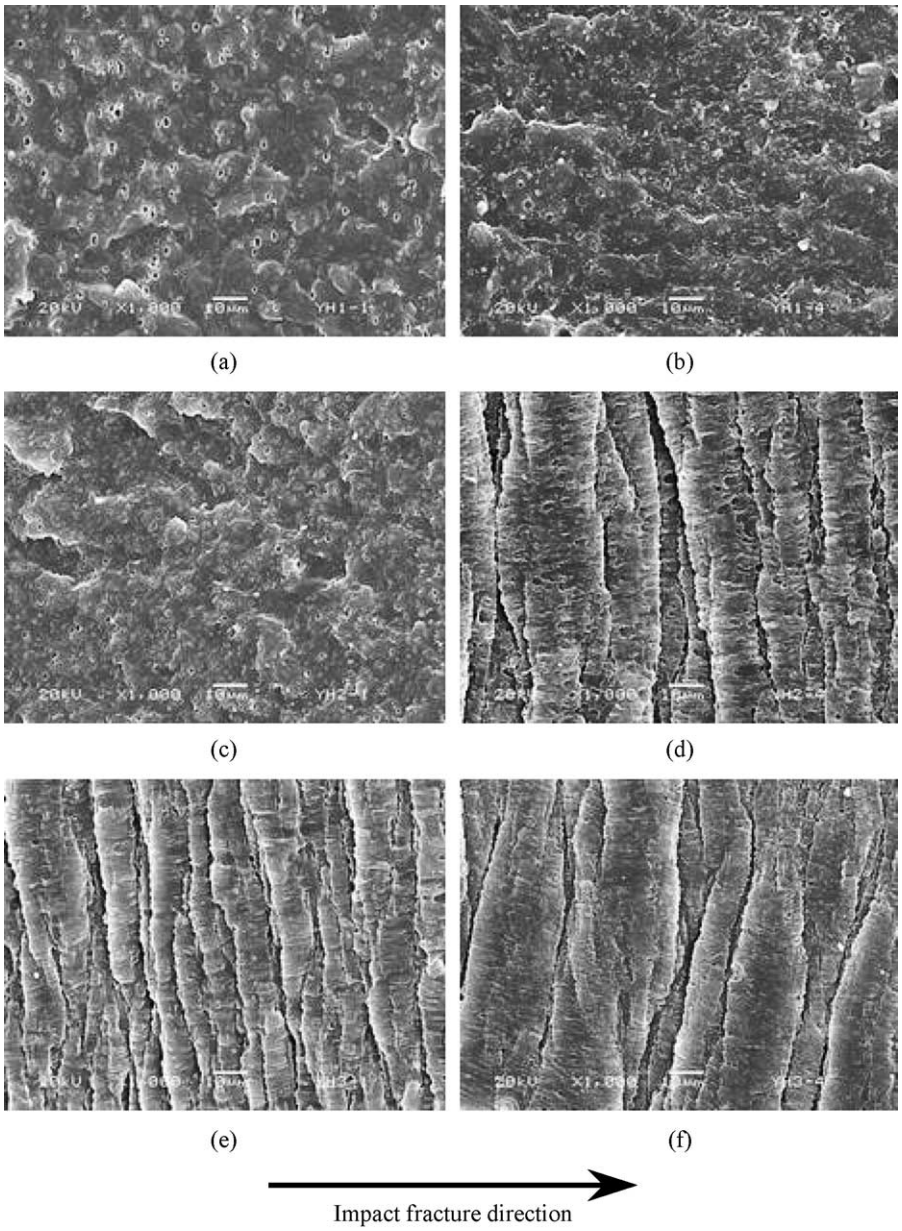


Fig. 9. SEM images of impact-fractured surface of PP/EPDM/B-SiO_2 composites PP/EPDM/B-SiO_2 (a) 90:10:0; (b) 90:10:5; (c) 80:20:0; (d) 80:20:5; (e) 70:30:0; (f) 70:30:5.

They reveal the typical morphology of a brittle failure; a relatively flat, smooth surface without any sign of deformation. The small, spherical holes seen in the fracture surface are probably due to the detachment of rubber or SiO_2 particles during the impact fracture (Fig. 9(a) and (b)). For PP/EPDM (80:20) binary composite, a smooth surface with many holes and some yielding sheets is seen (Fig. 9(c)), which suggests a relatively tough behavior. When adding 5 wt% B-SiO_2 particles, one observes many thick and long strips which are perpendicular to the impact fracture direction and are homogeneously distributed (Fig. 9(d)). The fracture process can be described as follows: when a ternary composite with such a microstructure, which is that SiO_2 particles aggregate around the EPDM particles and pervade over the PP matrix, is subjected to an impact loading, a large number of crazes will form in the PP matrix at the beginning of the loading. However, the crazes will be effectively stopped once large amounts of (SiO_2 core)–(EPDM shell) structure are formed and SiO_2 particles pervade over the PP matrix. So the propagation of the crazes will be forced into the direction perpendicular to the impact fracture direction, which enables the sample to sustain a higher loading. This is probably attributed to the overlap of stress fields around rubber particles with that around SiO_2 particles. One observes not much difference of the impact-fractured surface between PP/EPDM (70:30) binary composite and PP/EPDM/SiO_2 (70:30:5) ternary composite (Fig. 9(e) and (f)), indicating that in this case there is no need for SiO_2 particles to be the intermediate for the stress fields overlap between two rubber particles.

4. Conclusions

Using an appropriate processing method and adjusting the wettability of SiO_2 particles toward PP and EPDM, the phase structure of PP/EPDM/SiO_2 ternary composites can be successfully controlled. When hydrophilic SiO_2 particles (B-SiO_2) are blended with PP/EPDM composite by using two-step processing method, a unique phase structure that EPDM particles are closely surrounded by B-SiO_2 particles is obtained. Meanwhile, the Izod impact strength PP/EPDM (80:20) blends dramatically increases by adding B-SiO_2 particles. The remarkable increase in the Izod impact strength can be tentatively attributed to the overlap of the stress volume between EPDM and SiO_2 particles due to the formation of the SiO_2-surrounded EPDM particles. A more detailed work, including a calculation of the surface free energy, is need to better understand the formation of the phase morphology and toughening mechanism.

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