

Tensile Deformation and Fracture Mechanism of Highly Filled High-Density Polyethylene/Al(OH)₃ Composites

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ABSTRACT: The effect of the silicone oil content on the tensile properties and micromechanical deformation of high-density polyethylene/Al(OH)₃ composites was studied. With an increase in the silicone oil content, the elongation at break and notched Izod impact strength of the composites increased, and the local debonding deformation gradually transformed into homogeneous debonding deformation. A model characterizing the micromechanical deformation process was examined. The increase in the silicone oil content decreased the interaction between the filler particles and the high-density polyethylene matrix and increased the extension speed of the debonded region, which led to the changes in the tensile properties and micromechanical deformation. A good explanation for the tensile properties and micromechanical deformation was obtained through the model. © 2002 Wiley Periodicals, Inc. *J Appl Polym Sci* 85: 1207–1218, 2002

Key words: polyethylene (PE); fillers; microdeformation; flame retardance

INTRODUCTION

In previous publications,^{1,2} the effect of silicone oil on the mechanical properties of high-density polyethylene (HDPE) composites filled with 140 phr Al(OH)₃ was studied. The incorporation of silicone oil into the composites can increase the elongation at break from 1 to more than 200% and the notched Izod impact strength from less than 4 to more than 30 kJ/m². A later study³ showed that in the HDPE/Al(OH)₃/silicone oil composites, silicone oil encapsulates the filler particles to increase the elongation at break and impact strength of the composites. Other publications^{4–8} also showed that forming a soft interface between the filler particles and polymer matrix can increase the elongation at break and impact strength of highly filled polymer composites to a

great extent. Why can the soft interface between the filler particles and polymer matrix improve the mechanical properties so much? A satisfactory explanation for this has not yet been obtained.

Observing the micromechanical deformation process is a direct method for exploring the fracture mechanism of multiple-phase polymer materials.^{9–23} Michler and a coworker^{9–11} studied the structure–property correlations in multiple-phase polymer materials by *in situ* techniques with an electron microscope. The cavitation in rubber-toughened polymers and the debonding in particulate-filled polymers were studied in detail. Although the contribution of cavitation is minor in terms of enhanced toughness, this process plays an important role in promoting the shear yielding of the matrix ligaments between microvoids, which is the main method of absorbing the energy. Other publications^{12–18} also showed that cavitation has an important effect on the toughening mechanism of rubber-toughened polymers. The debonding process

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has also been studied.^{12,19–23} Many factors, such as the filler content,^{20–22} filler size,^{20,21} and interaction between the filler particles and the matrix,¹⁹ have been proven to affect the debonding process. The debonding process can affect the mechanical properties of particulate-filled polymers.^{19–22} Homogeneous debonding leads to tough fracture behavior, and local debonding leads to brittle behavior. However, further studies should be done to determine the relationship between the debonding process and mechanical properties.

In this study, the effect of the silicone oil content on the tensile properties and micromechanical deformation process of the highly filled HDPE/Al(OH)₃ composites were studied in detail. The correlation between the deformation process and the tensile properties was also examined. A model describing the micromechanical deformation process of the composites is proposed to interpret the experimental phenomena.

EXPERIMENTAL

Materials

HDPE 5000s (Yangtse Petroleum Chemical Co., Ltd., Nanjing, China), with a melt flow ratio of 0.923 g/10 min (2.16 kg at 190°C), was used as the matrix polymer. Al(OH)₃ (Apyral 60, Nabaltec Co., Ltd., Schwandorf, Germany), with a median particle size of 1.5 μm, was used as the filler. The surface treatment was performed with a 2 wt % titanate coupling agent (NDZ-130, Nanjing Shuguang Chemical General Co., Nanjing, China). Dimethyl silicone oil (Research Institute, Shanghai Special Resin Co., Shanghai, China) was used as an additive to improve the toughness of the HDPE/Al(OH)₃ composites.

All the components were mixed in the mixing chamber of a Haake RC90 rheometer (Haake Co., Karlsruhe, Germany) at 160°C and a rotor speed of 64 rpm for 15 min. Test specimens for morphological observations and mechanical property testing were prepared via compression molding at 165°C under a pressure of 15 MPa in the form of sheets 1.0 and 3.0 mm thick.

Tensile dumbbell specimens were cut from the 1-mm-thick sheets and tested with an Instron 4465 electron tensile tester according to Chinese Standard GB-1040-79 at a crosshead speed of 50 mm/min. Notched specimens 3 mm thick were tested in a Ray-Ran impact tester (Ray-Ran Test Equipment Ltd., Warwickshire, U.K.) according

to Chinese Standard GB-1043-79 at a hammer speed of 3.5 m/s and at a pendulum weight of 0.818 kg.

Investigation of the Micromechanical Deformation Process

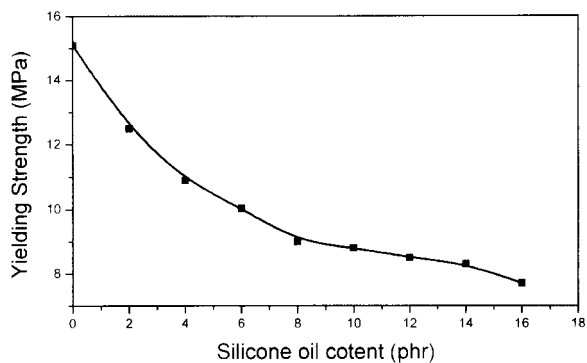
The samples for micromechanical deformation observations were obtained as follows. Tensile specimens of the HDPE/Al(OH)₃ composites incorporated with 0 or 8 phr silicone oil were stretched in the electron tensile tester at a crosshead speed of 2 mm/min. At several given elongations, the crosshead was stopped and sustained for 5 min, the deformed regions of the samples were cut down, and their side surfaces were golden-coated for scanning electric microscopy (SEM) observations. Tensile specimens of the HDPE/Al(OH)₃ composites incorporated with 2, 4, or 6 phr silicone oil were stretched in the electron tensile tester at a crosshead speed of 50 mm/min. The side faces of the fractured samples were golden-coated for SEM observations.

RESULTS AND DISCUSSION

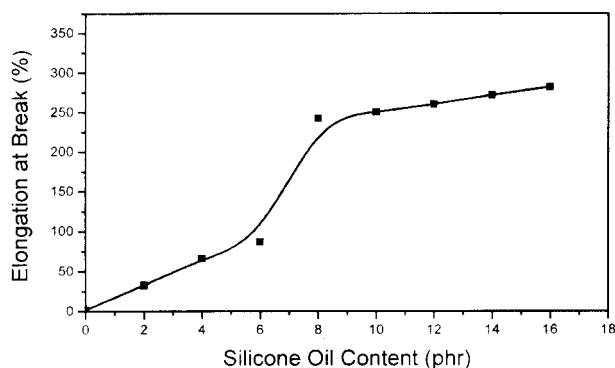
Mechanical Properties

The mechanical parameters characterizing the HDPE/Al(OH)₃ composites are shown in Figure 1 as functions of the silicone oil content. The large decrease in the yielding strength and the large increases in the elongation at break and impact strength occur with an increasing amount of silicone oil in the composites. There are some obvious transitions in the curves when the silicone oil content reaches 8 phr. After that, the slight decrease in the yielding strength and impact strength and the slight increase in the elongation at break occur with the increase in the silicone oil content. Previous studies^{2,3} showed that silicone oil becomes encapsulated around the filler particles in the HDPE/Al(OH)₃/silicone oil composites. When the silicone oil content reaches 8 phr, a perfect encapsulation structure forms, which is the reason the curves in Figure 1 transit in this silicone oil content.

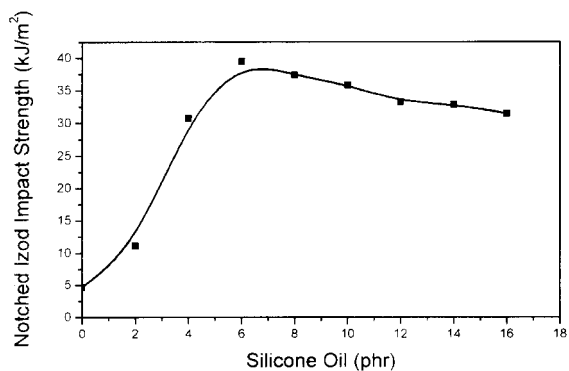
Figure 2 shows the stress–strain curves of the HDPE/Al(OH)₃ composites. Two types of stress–strain curves are obtained. When the silicone oil content is less than 8 phr, there are obvious yielding peaks in the curves, and there are no strain–harden phenomena. When the silicone oil content



(a)



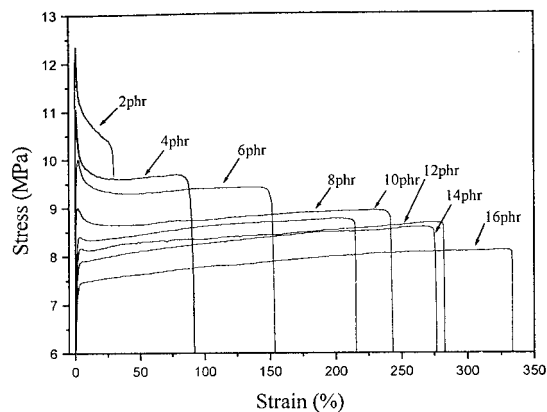
(b)



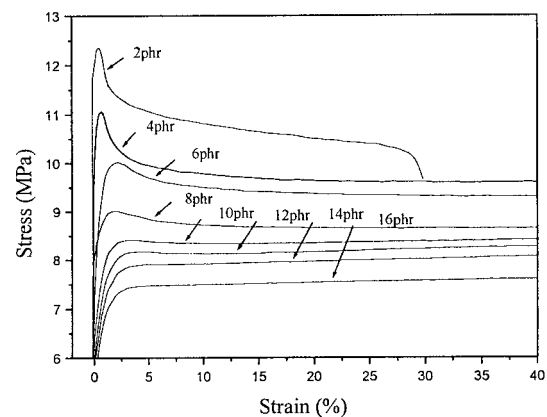
(c)

Figure 1 Effect of the silicone oil content on the mechanical properties: (a) yielding strength, (b) elongation at break, and (c) notched impact strength.

exceeds 8 phr, there is no yielding peak in the curves, and there are slight strain-hardening phenomena. The relationship between the silicone oil content and the difference between the peak stress and equilibrium stress in the stress-strain



(a)



(b)

Figure 2 Effect of the silicone oil content on the stress-strain curves.

curves of the HDPE/Al(OH)₃ composites is shown in Figure 3. With the increase in the silicone oil content, the difference between the peak stress and equilibrium stress in the stress-strain curves

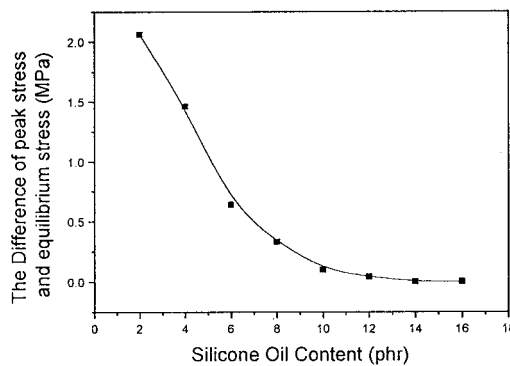


Figure 3 Effect of the silicone oil content on the difference between the peak and equilibrium stress.

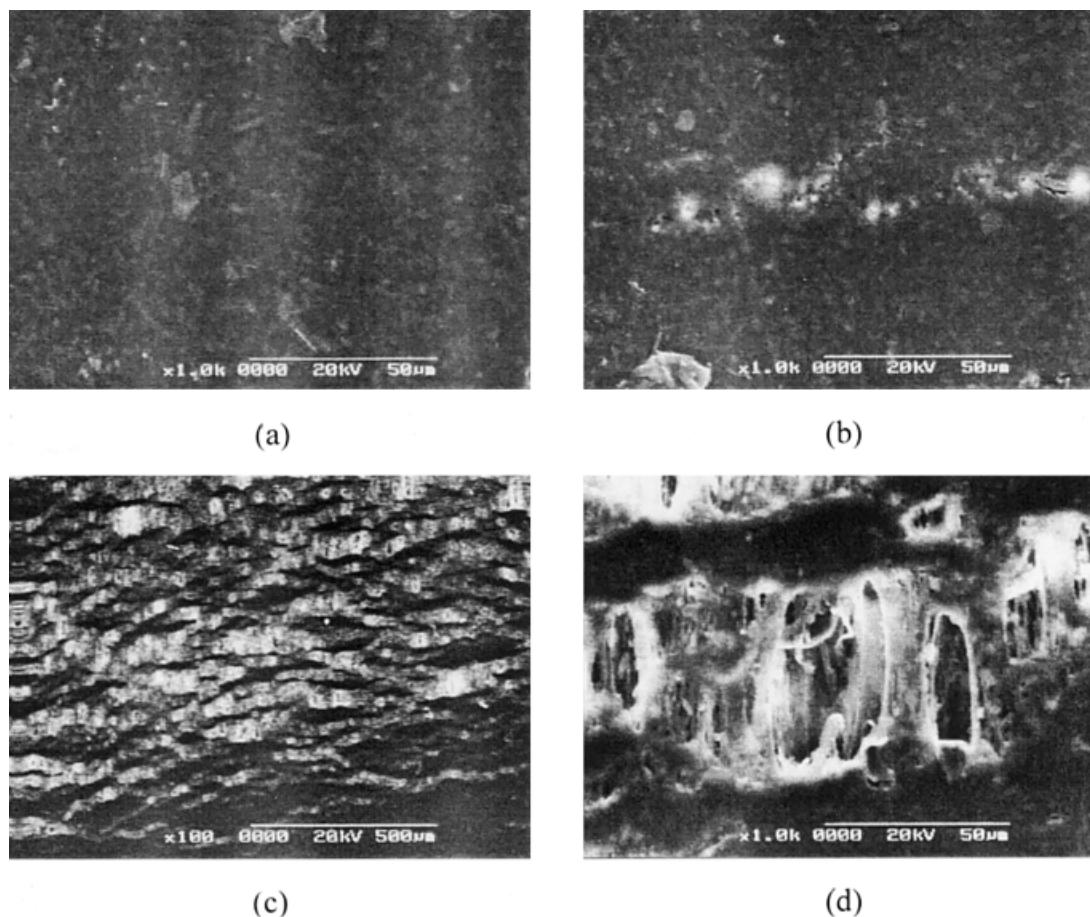


Figure 4 SEM micrographs of the surfaces of the stretched HDPE/Al(OH)₃ composite without silicone oil: (a) before yielding, (b) yielding, (c) fracture in low magnification, and (d) fracture in high magnification.

decreases. When the silicone oil content exceeds 8 phr, the difference is nearly zero.

The encapsulation structure of silicone oil around the filler particles reduces the interaction between the filler particles and the HDPE matrix, which leads to the decrease in the debonding strength. When the silicone oil content reaches 8 phr, a perfect encapsulation structure forms, which leads to zero debonding strength.³ Figure 2 shows that when the silicone oil content exceeds 8 phr, there is no yielding peak in the stress–strain curves. This shows that there are no peak-yielding phenomena in the plastic deformation of the matrix ligaments between the filler particles in the HDPE/Al(OH)₃ composites. Therefore, the yielding peaks in the stress–strain curves of the HDPE/Al(OH)₃ composites incorporated with less than 8 phr silicone oil originate from the interaction between the filler particles and the HDPE matrix. With the increase in the silicone oil con-

tent, the interaction between the filler particles and the HDPE matrix decreases. Therefore, the yielding stress of the composites decreases with the increase in the silicone oil content. When the silicone oil content reaches 8 phr, a perfect encapsulation structure forms, which removes the interaction between the filler particles and the HDPE matrix and leads to stress–strain curves without any yielding peaks.

Micromechanical Deformation

There are obvious differences in the tensile morphologies of the HDPE/Al(OH)₃ composites. A neck structure forms in the tensile process of the composites incorporated with less than 8 phr silicone oil. With the increase in the silicone oil content, the length of the neck region increases. When the silicone oil content exceeds 8 phr, there is no neck structure, and the samples deform homogeneously.

Figure 4 shows the micromechanical deformation process of the HDPE/Al(OH)₃ composite without silicone oil. Before tensile deformation, the surface of the sample is smooth, as shown in Figure 4(a). When the sample yields, a cracklike structure can be observed that crosses to both sides of the sample perpendicularly to the loading direction, as shown in Figure 4(b). When the sample fractures, a zone with bounds of cracklike structures is seen near the fracture surface in low magnification [Fig. 4(c)]. In a high-magnification micrograph, large plastic deformation of the matrix ligaments between the filler particles can be seen in the cracklike regions, and numerous voids can be found [Fig. 4(d)]. Some fractured matrix ligaments that have developed large deformation can also be seen. Although the elongation at break of the composite is only 1.8%, the local elongation near the fracture region, which is defined as the longitudinal elongation of the pores developed in the tensile process, is almost 300%.

Figure 5 shows the micromechanical deformation process of the HDPE/Al(OH)₃ composite incorporated with 8 phr silicone oil. Before tensile deformation, the surface of the sample is smooth [Fig. 5(a)]. When the sample yields, several cracks, perpendicular to the loading direction and not across to the sides of the sample, can be found in a local region of the sample [Fig. 5(b)]. When the elongation is nearly 20%, the cracklike structures homogeneously develop over the entire surface of the sample [Fig. 5(c)]. When the elongation is nearly 50%, the cracklike structures develop into homogeneous void structures over the entire sample [Fig. 5(d)]. When the sample fractures at 300% elongation [Fig. 5(e)], many voids can be seen on both sides of the particles in the direction parallel to the applied stress that are formed by plastic deformation of the matrix between particles after the debonding process. The void structure is distributed homogeneously all the entire sample. The local elongation of the sample is nearly 300%, equal to the elongation at break of the sample.

Figure 6 shows the morphological characteristics of the side faces of the fractured HDPE/Al(OH)₃ composite incorporated with 4 phr silicone oil. From the fracture surface to the ends of the debonded region, several places, between which the distances were almost the same, were chosen for the SEM micrographs. Three conclusions can be drawn from these SEM micrographs. First, a large amount of plastic deformation occurs in the region adjacent to the fracture surface,

and the local elongation in this region is nearly 300%, which is larger than the elongation at break of the composites. Second, from the fracture surface to the ends of the debonded region, the local elongation of the composites decreases continually. At the end of the debonded region, the local elongation is very small, which shows that the debonding deformation is just initiated; this is similar to the deformation shown in Figure 5(c). In the region adjacent to the fracture surface, the local elongation is nearly 300%, which is similar to the deformation shown in Figure 5(e). Third, from the fracture surface to the end of the debonded region, the grade of the local elongation decreases. The same phenomena were also seen in the HDPE/Al(OH)₃ composites incorporated with 2 and 6 phr silicone oil.

The micromechanical deformation process of the HDPE/Al(OH)₃ composites is different from that of neat HDPE. In the tensile process of neat HDPE, an obvious neck structure can be observed, and plastic deformation mainly occurs at the edge of the neck before the neck structure develops to the ends of the sample. There is almost no plastic deformation in the neck region because of the strain–harden phenomenon. The strain rate of the HDPE sample is only considered the result of the plastic deformation at the edge of the neck, so the local strain rate of the edge is very high, which leads to an obvious neck structure. In the HDPE/Al(OH)₃ composites, plastic deformation occurs in the whole neck region (Figs. 5 and 6). The strain rate of the HDPE/Al(OH)₃ composites is considered the result of the deformation of the whole neck region. With the increase in silicone oil, the length of the neck region increases, and the local strain rate of the neck region decreases, which makes the neck structure more and more blurry. There is no strain–harden phenomenon in the composites. When the local elongation reaches nearly 300%, the composites fracture.

Model of the Micromechanical Deformation of the HDPE/Al(OH)₃ Composites

On the basis of morphological studies, the micromechanical deformation process of the highly filled HDPE/Al(OH)₃ composites can be described with the sketches shown in Figure 7.

Initiation of Micromechanical Deformation

Debonding deformation is initiated in a narrow zone perpendicular to the loading direction when

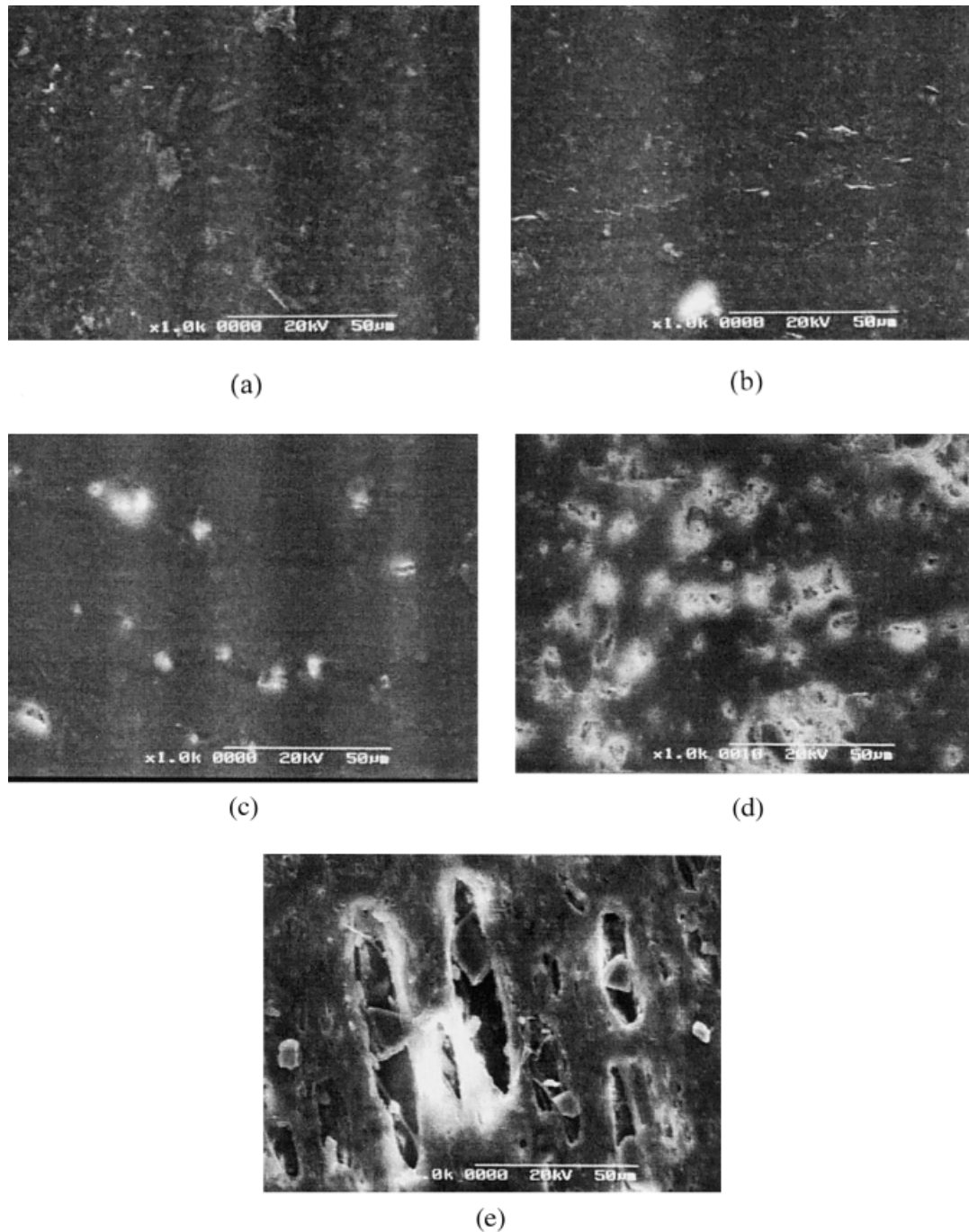


Figure 5 SEM micrographs of the surfaces of the stretched HDPE/Al(OH)₃ composite with 8 phr silicone oil: (a) before yielding, (b) yielding, (c) after yielding, (d) 50% elongation, and (e) fracture.

the load reaches the yielding stress [Fig. 7(b)]. This process forms a cracklike structure in the side faces of the HDPE/Al(OH)₃ composites perpendicular to the loading direction [Figs. 4(b) and 5(b)].

Extension of Debonding Deformation

After the debonding deformation is initiated, the debonding deformation will extend to both sides of the tensile samples in the loading direction

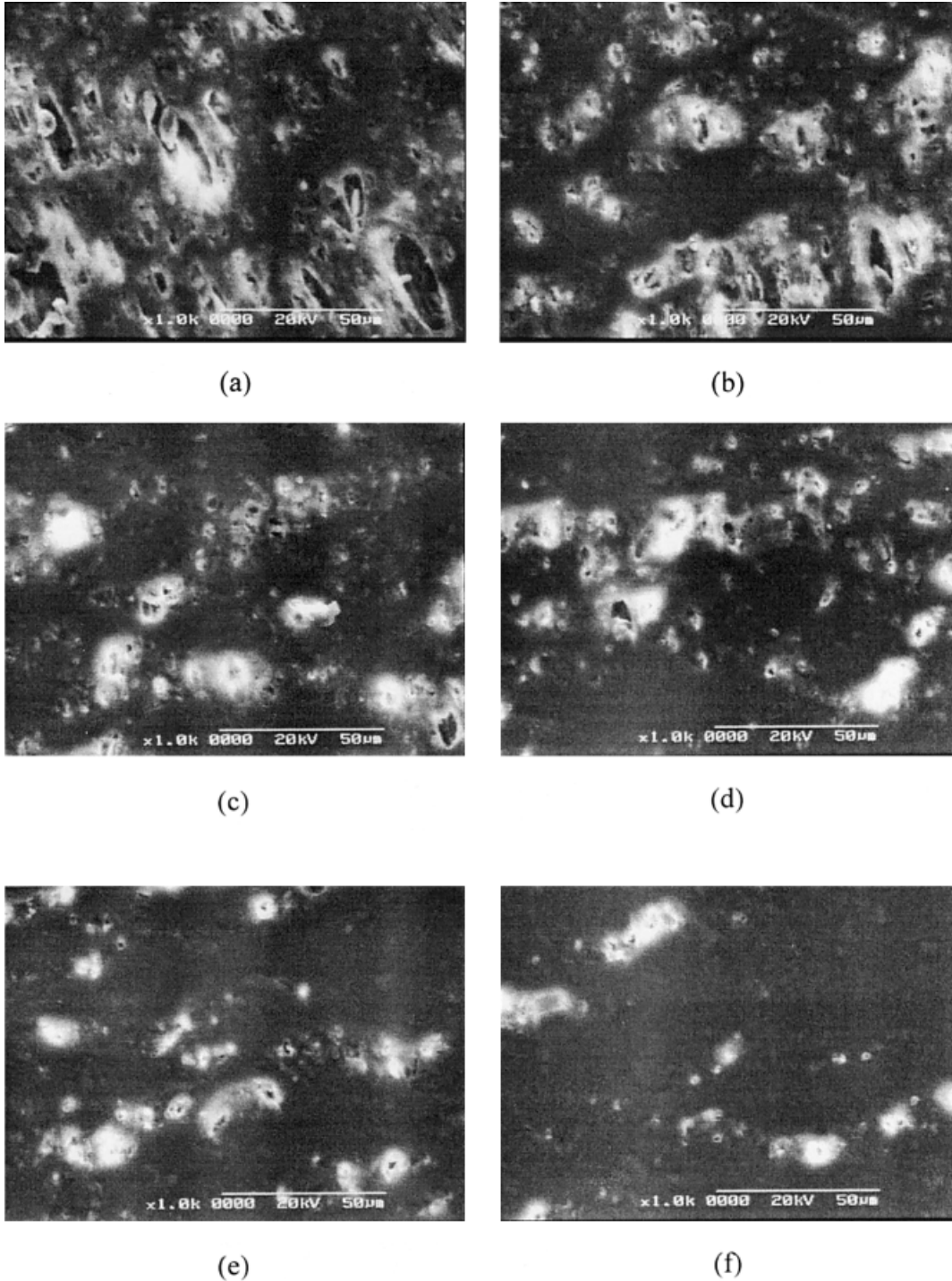


Figure 6 SEM micrographs of the surfaces of the stretched HDPE/AL(OH)₃ composite incorporated with 4 phr silicone oil content.

[Fig. 7 (c)]. This process increases the length of the debonded region, that is, the deformed region or neck region, in which the matrix is pulled out from the surfaces of the filler particles. The extending process of the debonded region of the

composites is not the same as that of the neck region of neat HDPE. Large plastic deformation occurs at the edges of the neck region of neat HDPE in the extending process of the neck region. However, only slight plastic deformation oc-

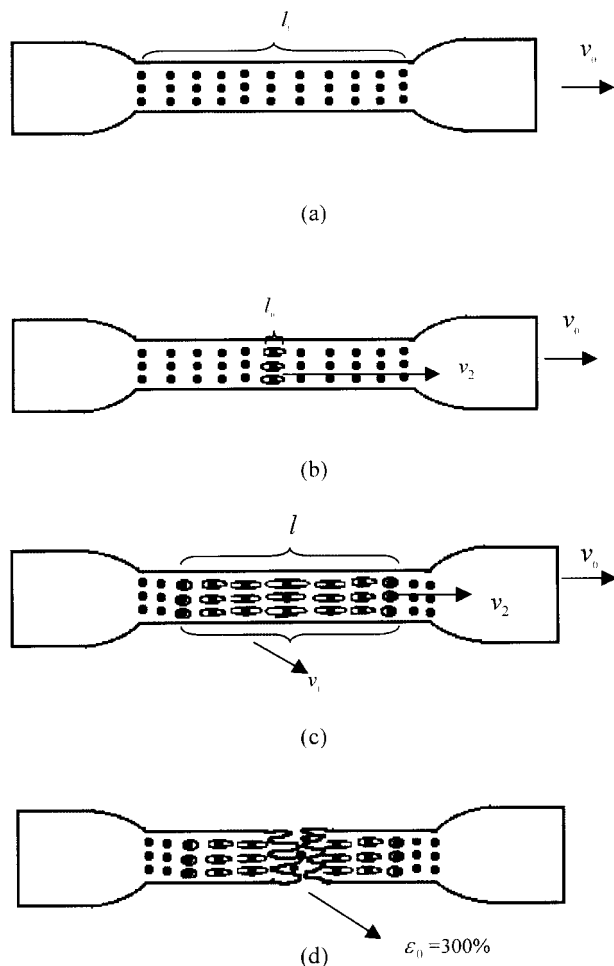


Figure 7 Sketch of the tensile deformation process of HDPE/Al(OH)₃ composites: (a) before tensile deformation, (b) debonding initiation, (c) extension and deformation of debonding region, and (d) fracture.

occurs at the edges of the neck region of the HDPE/Al(OH)₃ composites [Fig. 6]. The extending process of debonding deformation just increases the length of the deformed region and can hardly increase the length of the whole sample.

The speed of the extension of the debonded region is affected by the following two factors. One is the plastic deformation strength of the debonded region, that is, the equilibrium stress in stress–strain curves of the composites, which is affected by the filler content. The other is the debonding strength, which is affected by the interaction between the filler particles and the HDPE matrix. Dubnilova and coworkers^{20,21} argued that the tensile morphologies of the polypropylene/Al(OH)₃ composites are controlled by the relationship between the plastic deformation

strength of the debonded region (σ^{cz}) and the debonding strength (σ_d). σ^{cz} is calculated as follows:

$$\sigma^{cz} = \sigma^{ch}(1 - \alpha \cdot \phi^{2/3})$$

where σ^{ch} is the plastic deformation strength of neat polymers, ϕ is the volume fraction of the filler, and α is the fraction of debonded filler particles. When σ^{cz} is greater than σ_d , the debonded region can extend to both sides in the loading direction, which leads to the macrohomogeneous character of the flow and tough fracture. When σ^{cz} is less than σ_d , the debonded region cannot be extended, which leads to a sharp localization of macroscopic yielding and quasibrittle fracture. We studied in detail the situation in which σ^{cz} is greater than σ_d . For the HDPE/Al(OH)₃ composites at a given filler content, σ^{cz} is a fixed value. Therefore, the extension speed of the debonded region is controlled by the value of σ_d . With the increase in the silicone oil content, the interaction between the filler particles and the HDPE matrix decreases, and the value of σ_d decreases, which leads to an increase in the extension speed.

Deformation of the Debonded Region

The deformation of the debonded region of the HDPE/Al(OH)₃ composites is different from the neck region of neat HDPE. In the tensile process of neat HDPE, plastic deformation mainly occurs at the edges of the neck region; there is hardly any plastic deformation in the middle of the neck region because of the strain–harden phenomenon. Therefore, the strain rate of HDPE is considered the result of the deformation of the neck edges. In the tensile process of the HDPE/Al(OH)₃ composites, the debonded region deforms homogeneously, and the local strain rate of any part of the region is the same [Fig. 7(c)]. The strain rate of the composites is considered the result of the deformation of the whole debonded region. However, why are the local elongations in the debonded region different (Fig. 6)? It is the different deformation history that leads to the difference in local elongation. From the fracture surface to the ends of the debonded region, the deforming time of the local regions decreases continually, which leads the local elongations to decrease continually. The region near the fracture surface experiences the longest deforming time, so the local elongation of this region is the largest. In the region near the ends of the debonded re-

gion, debonding deformation is just initiated, so the local elongation of this region is nearly zero.

Fracture

When the local elongation of the debonded region reaches a fixed value, defined as the local elongation at break, the composites fracture [Fig. 7 (d)]. There are no strain–harden phenomena in the tensile process. The local elongation at break of the HDPE/Al(OH)₃ composites studied in this article is nearly 300% [Figs. 4(d), 5(e), and 6(a)]. The morphologies show that the local elongation at break is hardly affected by the interaction between the filler particles and the HDPE matrix. It is controlled by the filler content. Because the local elongation of the debonding-initiated region is the largest, the composites always fracture in this region.

It is very important that there are no strain–harden phenomena in the tensile process of the HDPE/Al(OH)₃ composites; this makes it simple to judge the fracture of the composites. The studies by Dubnikova and coworkers^{21,22} revealed that the strain–harden phenomena in polypropylene/Al(OH)₃ composites disappear when the Al(OH)₃ content exceeds 20 vol %. Therefore, the model of micromechanical deformation proposed in this article is just applicable to highly filled polymers, which have no strain–harden phenomena during the tensile process.

Calculating the Elongation at Break of the HDPE/Al(OH)₃ Composites

The constant parameters in the model are (1) l_1 (mm), the length of the parallel part of the tensile sample [Fig. 7(a)]; (2) ν_0 (mm/min), the crosshead speed; (3) ν_2 (mm/min), the extension speed of the debonded region [Fig. 7(c)]; (4) ε_0 (%), the local elongation at break of the composites, or the local elongation of the fractured region; and (5) l_0 (mm), the length of the initial debonded region, after which stable extension of the debonded region occurs [Fig. 7 (b)]. In this article, the value of l_0 is defined as 2 μm , about the diameter of the filler particles.

The variables in the model are (1) l (mm), the length of the debonded region [Fig. 7(c)], the value of which increases continually during the tensile process; (2) t (min), the tensile time; (3) ν_1 (min^{-1}), the local strain rate of the debonded region when the tensile time is t [Fig. 7(c)]; (4) g (mm), the length of the initial debonded region

when the tensile time is t ; (5) t_f (mm), the fracture time, or the tensile time that the tensile sample experiences before fracturing; (6) ε (%), the local elongation of the initial debonded region; and (7) ε_f (%), the elongation at break of the whole parallel part of the tensile sample.

Relationship between ν_1 and l

The debonded region deforms homogeneously, so the local strain rates of the debonded regions are the same. The relationship between ν_1 and l is

$$\nu_1 \cdot l = \nu_0 \quad (1)$$

ν_1 decreases with an increase in l .

Relationship between ν_1 and t

The increase in l depends on two factors. One is the deformation of the debonded region. The other is the extension of the debonded region. If the debonding deformation is initiated in the middle of the tensile samples, the time when the debonded region reaches the ends of the samples is $l_1/(2\nu_2)$. The relationship between l and t can be given as follows.

$$\text{If } t < \frac{l_1}{2\nu_2}$$

$$l = l_0 + (\nu_0 + 2\nu_2) \cdot t \quad (2)$$

From eqs. (1) and (2), the relationship between ν_1 and t is

$$\nu_1 = \frac{\nu_0}{[l_0 + (\nu_0 + 2\nu_2) \cdot t]} \quad (3)$$

$$\text{If } t > \frac{l_1}{2\nu_2}$$

$$l = (l_0 + l_1) + \nu_0 \cdot t \quad (4)$$

From eqs. (1) and (4), the relationship between ν_1 and t is

$$\nu_1 = \frac{\nu_0}{[(l_0 + l_1) + \nu_0 \cdot t]} \quad (5)$$

Relationship between ε and t

In the tensile process, the local elongation of the initial debonded region is the largest in the debonded region. When the local elongation of this region reaches ε_0 , the tensile sample fractures. The local elongation of the initial debonded region can be calculated as

$$\varepsilon = \frac{g}{l_0} - 1 \tag{6}$$

where g is the length of the initial debonded region when the tensile time is t . The increment of the length of the initial debonded region is given by the relationship

$$dg = g \nu_1 \cdot dt \tag{7}$$

$$\text{If } t < \frac{l_1}{2\nu_2}$$

the boundary condition is

$$t = 0, \quad l = l_0$$

Integrating eq. (7) yields

$$\int_0^g dg = \int_0^t g \nu_1 \cdot dt \tag{8}$$

From eqs. (3), (6), and (8), the relationship between ε and t is

$$\ln(1 + \varepsilon) = \left(\frac{\nu_0}{\nu_0 + 2\nu_2}\right) \cdot \ln\left[1 + \left(\frac{\nu_0 + 2\nu_2}{l_0}\right) \cdot t\right] \tag{9}$$

$$\text{If } t < \frac{l_1}{2\nu_2}$$

the boundary condition is

$$t = 0, \quad l = l_0$$

Integrating eq. (7) yields

$$\int_0^g dg = \int_0^{l_1/2\nu_2} g \nu_1 \cdot dt + \int_{l_1/2\nu_2}^g g \nu_1 \cdot dt \tag{10}$$

From eqs. (3), (5), (6), and (10), the relationship between ε and t is

$$\ln(1 + \varepsilon) = \left(\frac{\nu_0}{\nu_0 + 2\nu_2}\right) \cdot \ln\left[1 + \left(\frac{\nu_0 + 2\nu_2}{l_0}\right) \cdot \left(\frac{l_1}{2\nu_2}\right)\right] + \ln\left[\frac{(l_0 + l_1) + \nu_0 t}{(l_0 + l_1) + \nu_0 \cdot \frac{l_1}{2\nu_2}}\right] \tag{11}$$

Calculating the Elongation at Break of the Parallel Parts of the Composites

Substituting $\varepsilon = \varepsilon_0$ into eqs. (9) and (11) can yield t_f

$$\text{If } t_f < \frac{l_1}{2\nu_2}$$

$$t_f = \left(\frac{l_0}{\nu_0 + 2\nu_2}\right) \cdot [(1 + \varepsilon_0)^{(1+2\nu_2/\nu_0)} - 1] \tag{12}$$

$$\text{If } t_f < \frac{l_1}{2\nu_2}$$

$$t_f = \left(\frac{l_0 + l_1}{\nu_0} + \frac{l_1}{2\nu_2}\right) \cdot (1 + \varepsilon_0) \cdot \left\{1 + \left(\frac{l_1}{l_0}\right) \cdot \left(1 + \frac{\nu_0}{2\nu_2}\right)\right\}^{(2\nu_2/\nu_0 + 2\nu_2 - 1)} - \left(\frac{l_0 + l_1}{\nu_0}\right) \tag{13}$$

The relationship between the elongation at break of the whole parallel part of the tensile sample, ε_f , and t_f is

$$\varepsilon_f = \frac{\nu_0 \cdot t_f}{l_1} \tag{14}$$

From eqs. (12)–(14), the value of ε_f is

$$\text{If } t_f < \frac{l_1}{2\nu_2}$$

$$\varepsilon_f = \left(\frac{l_0}{l_1}\right) \cdot \left(\frac{\nu_0}{\nu_0 + 2\nu_2}\right) \cdot \{(1 + \varepsilon_0)^{(1+2\nu_2/\nu_0)} - 1\} \tag{15}$$

$$\text{If } t_f > \frac{l_1}{2\nu_2}$$

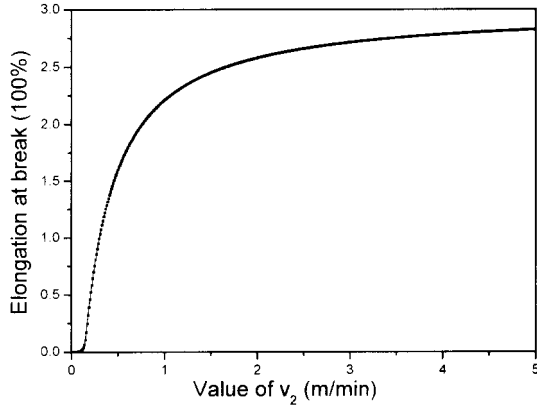


Figure 8 Relationship between ε_f and ν_2 .

$$\varepsilon_f = \left(\frac{l_0 + l_1}{l_1} + \frac{\nu_0}{2\nu_2} \right) \cdot (1 + \varepsilon_0) \cdot \left\{ 1 + \left(\frac{l_1}{l_0} \right) \cdot \left(1 + \frac{\nu_0}{2\nu_2} \right) \right\}^{(2\nu_2/\nu_0 + 2\nu_2 - 1)} - \left(\frac{l_0 + l_1}{l_1} \right) \quad (16)$$

In this article, the value of ν_0 is 0.05 m/min, the value of l_1 is 0.045 m, the value of l_0 is 2×10^{-6} m, and the value of ε_0 is 300%. On the basis of eqs. (12), (13), (15), and (16), the relationship between ε_0 and ν_2 is described in Figure 8. It is very clear that the value of ε_f increases with the increase in the value of ν_2 . First, in the HDPE/Al(OH)₃ composite without silicone oil, the interaction between the filler particles and the HDPE matrix is strong, and ν_2 is nearly zero. Therefore, ε_f is nearly zero. Second, in the HDPE/Al(OH)₃ composites incorporated with more than 8 phr silicone oil, a perfect encapsulation structure forms, which leads to zero interaction between the filler particles and the HDPE matrix. In this case, ν_2 is nearly infinite. Therefore, ε_f is nearly 300%, the value of ε_0 . Third, in the HDPE/Al(OH)₃ composites with less than 8 phr silicone oil, the interaction between the filler particles and the HDPE matrix decreases with the increase in the silicone oil content, which makes ν_2 increase with the increase in the silicone oil content. Therefore, ε_f increases with the increase in the silicone oil content.

DISCUSSION

In the morphological analysis, three conclusions are drawn. They can be explained with the micromechanical deformation model. First, the local

elongations at break of the HDPE/Al(OH)₃ composites are all nearly 300%. According to the model, the local elongation at break is only controlled by the filler content, and it cannot be affected by the interaction between the filler particles and the HDPE matrix. Second, from the fracture surface to the ends of the debonded region, the local elongation of the composites decreases. On the basis of the model, although the local strain rates of the debonded region are the same, different places of the debonded region experience different deformation histories. From the fracture surface to the ends of the debonded region, the deformation time increases, so the local elongation increases. Third, from the fracture surface to the end of the deformed region, the grade of the local elongation decreases. According to the model, with the increase in the length of the debonded region, the value of ν_1 decreases, but the value of ν_2 does not vary. From the fracture surface to the ends of the debonded region, two regions of equal length are chosen. Although the sides of the two regions near the fracture surface experience the same deformation time more than the sides near the ends of the debonded region, larger elongation occurs in the region near the fracture surface because of the decrease in the value of ν_1 from the fracture surface to the ends of the debonded region. Therefore, the difference between the two sides of the region near the fracture surface is larger than that of the region near the ends of the debonded region.

CONCLUSIONS

The micromechanical deformation process of the HDPE/Al(OH)₃ composites has been studied in detail. The silicone oil content greatly affects both the mechanical properties and micromechanical deformation of the composites. With an increase in the silicone oil content, the elongation at break and notched impact strength of the composites are increased to a great extent, and local yielding morphologies transit into macrohomogeneous deformation gradually. A model is proposed to describe the micromechanical deformation process. On the basis of the model, the deformation process of the HDPE/Al(OH)₃ composites includes three steps. They are the initiation of the debonded region, the deformation and extension of the debonded region, and the fracture of the composites. Silicone oil encapsulates around filler particles, decreasing the interaction between the

filler particles and the HDPE matrix, which leads to the great increase in the extension speed of the debonded region. It is the reason silicone oil can affect the mechanical properties and micromechanical deformation process so much.

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