

Preparation and Properties of Polyethylene Terephthalate/ Polyethylene/Near Infrared Reflective Pigment Composites

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ABSTRACT: Polyethylene terephthalate/high density polyethylene (PET/HDPE) composites containing a near infrared reflective (NIR, nickel antimony titanium yellow rutile) pigment was prepared using ethylene-glycidyl methacrylate-vinyl acetate (EGMA-VA) as a compatibilizer to increase the infrared reflection of PET/HDPE and limit the thermal heat accumulation in light of environmental and energy conservation concerns. HDPE was premixed with NIR to form N-HDPE masterbatch. A good interfacial bonding between PET matrix and HDPE dispersed phase with the help of compatibilizer was confirmed through Fourier transform-infrared spectra, scanning electron microscopy, and torque rheometer. For PET/N-HDPE composites, the major X-ray diffraction peaks and melting behaviors remained unchanged, indicating the limited alternation of crystalline structure for the composite systems with or without compatibilizer. The observed increment in the crystallization temperature of PET for the investigated PET/N-HDPE composites was mainly due to the nucleation role of both inorganic NIR and HDPE. Tensile strength and elongation at break for compatibilized cases at various N-HDPE contents conferred higher values than those of the corresponding counterparts without compatibilizer. Yet, Young's modulus for compatibilized systems was about 40% lower than that for systems without compatibilizer, attributed to the rubbery nature of EGMA-VA. With the inclusion of NIR into HDPE to form PET/N-HDPE composites with or without EGMA-VA compatibilizer, the values of reflectance increased to a great degree. © 2014 Wiley Periodicals, Inc. *J. Appl. Polym. Sci.* **2014**, *131*, 40830.

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INTRODUCTION

Polymer blending technology offers a cost-benefit approach in developing novel polymeric materials without having a significant environmental impact because of the limited use of solvent. Thus, it has been widely adopted as a major product development protocol in the academia and industry. Utracki reviewed various polymer blends and composites development in the past decades.¹ Polyethylene terephthalate (PET) is a widely used polymer in the area of packaging and fiber industry. To further expand its application, a blending technique to form PET blends and composites become a facile approach. In most cases, a compatibilizer or surface modified filler was often required in order to improve the interfacial reaction between PET and other polymers/fillers due to the compatibility problem. Among those polymers, a cost competitive polyolefin is the most widely used polymer in the industry and several attempts

have been made regarding the PET/polyolefin/filler composites to endow with the functionality and to balance the stiffness as well as toughness for PET.²⁻⁶

Ihm and White² investigated several types of compatibilizers for PET/PE blends, such as polybutylene terephthalate-polyethylene-*block*-copolymer (PBT-*b*-PE), polystyrene-(ethylene/butylene)-styrene triblock copolymer (SEBS), ethylene-vinyl acetate copolymer (EVA), hydrogenated butadiene-acrylonitrile copolymer (HNBR), ethylene-propylene copolymer (EPR), MA functionalized HDPE (MA-*f*-HDPE), MA functionalized polypropylene (MA-*f*-PP), MA functionalized EVA (MA-*f*-EVA), and MA functionalized SEBS. Among these compatibilizers, PBT-*b*-PE and MA functionalized types outperformed others to reduce the interfacial energy between PET and PE. Jin et al.⁶ applied a special approach in restricting conductive carbon black in the PE co-continuous phase via the titanium coupling

Table I. Formulation for PET/N-HDPE/EGMA-VA Blends and Composites

Sample code	PET (g)	HDPE (g)	NIR (g)	EGMA-VA (g)
PET/N-HDPE/EGMA-VA 0 phr	80	20	6.7	-
	60	40	13.3	-
	50	50	16.7	-
	40	60	20	-
PET/N-HDPE/EGMA-VA 10 phr	80	20	6.7	10
	60	40	13.3	10
	50	50	16.7	10
	40	60	20	10

Blend composition of HDPE and NIR is fixed at a weight ratio of 3/1.

agent for PET/PE blends. This unique way could prevent a high dosage of carbon black from a difficulty in processing and deterioration in mechanical properties. The percolation threshold could reduce from 15% to 8% with 2% coupling agent for a PET/PE blend ratio of 60/40. In this study, we will adopt a similar approach by premixing a functional near infrared reflective pigment (NIR, nickel antimony titanium yellow rutile) into the PE phase and use a different compatibilizer to improve the blend performance.

Recently, functional near infrared reflective pigments have received much attention in light of environmental and energy conservation concerns, as they could reflect much of infrared ray, a major source accounting for the thermal heat accumulation. In general, most of these pigments have been applied in the coating system to have a better performance and efficiently reduce the thermal accumulation in the building and construction fields to limit the significant heat island scenario.^{7–12} Jose and Reddy⁷ designed novel blue inorganic pigments to outperform commercially available cobalt blue pigment, and their developed pigments possessed high NIR solar reflectance. Levinson et al.¹³ indicated that the solar power distribution consists of ultraviolet (5%), visible light (43%), as well as near IR (52%), and the use of layers of antireflective coating could reduce the thermal accumulation effect to a certain degree. For the applications other than the conventional coating systems, our recent work also applied those functional pigments to increase the near infrared reflection values of neat PET¹⁴ via a melt blending process. Gulrez et al.¹⁵ recently reported the improved NIR reflective properties for NIR-reflective polyethylene greenhouse films and the tensile strength was about the same as that of control resin. Bendiganavale and Malshe¹⁶ recently reviewed the related patents and researches on the potential applications of near infrared reflective pigments, such as military, automobile, textile materials, besides their conventional roof application. For those potential applications, the mechanical properties, thermal properties, etc. were also required to some extent besides the demand of NIR reflectivity. It is worthwhile to investigate how these functional pigments could be applied in different applications to make the most of their advantages.

Even though various PET/polyolefin/filler composites were investigated in the literature, to the authors' best knowledge,

this is the first study in incorporating NIR filler into the PET/PE blends without using a coating approach to avoid a solvent impact, and combining the versatile properties of both PET/PE blends and NIR materials using a compatibilizer. In order to investigate the dispersion effect, PET/HDPE/NIR composites with or without compatibilizer, ethylene-glycidyl methacrylate-vinyl acetate (EGMA-VA), was prepared. HDPE was premixed with NIR to form N-HDPE masterbatch. This work aims to assess this effect on the NIR dispersion, dynamic mechanical properties, thermal properties, mechanical properties, and infrared reflection properties to contrast the significance of the compatibilizer and NIR modification in the PET/HDPE/NIR blends and composites.

EXPERIMENTAL

Materials

The materials used in this study were PET, HDPE, and NIR (Near infrared reflection pigment). Nickel antimony titanium yellow rutile is a NIR reflectance pigment (NIR) with the average primary particle size of about 1 to 2 μm , supplied by Tokan Material Technology Company under the trade name of 42–401 A. The PET (9 EF 04) with an intrinsic viscosity of 0.805 dL/g was supplied by Son Cho Technology Corporation (Taiwan). HDPE (Unithene LH 901) with a melt flow index of 0.95 g/10 min was supplied from USI Corporation. Ethylene/glycidyl methacrylate/vinyl acetate (EGMA-VA, Sumitomo Chemical Company, IGETABOND® 2B) with a melt flow index of 3 g/10 min was used as a compatibilizer. Its glycidyl methacrylate grafting level and vinyl acetate are reported to be 12 wt % and 5 wt %, respectively.

Sample Preparations

All pristine resins were predried in a vacuum oven prior to mixing. HDPE and NIR were predried for 4 hr at 80°C, and PET was predried for 4 hr at 110°C. In addition, EGMA-VA was predried for 6 hr at 50°C. Two steps of melt-blending were performed. At first, the blend composition of HDPE and NIR fixed at a weight ratio of 3/1 was mixed under 50 rpm at 180°C for 10 min using a batch mixer (Brabender 815605, Plastograph) to form NIR-filled HDPE (N-HDPE). In the second step mixing, this NIR-filled HDPE composite was mixed with both PET and EGMA-VA under 50 rpm at 250°C for 10 min. The composition

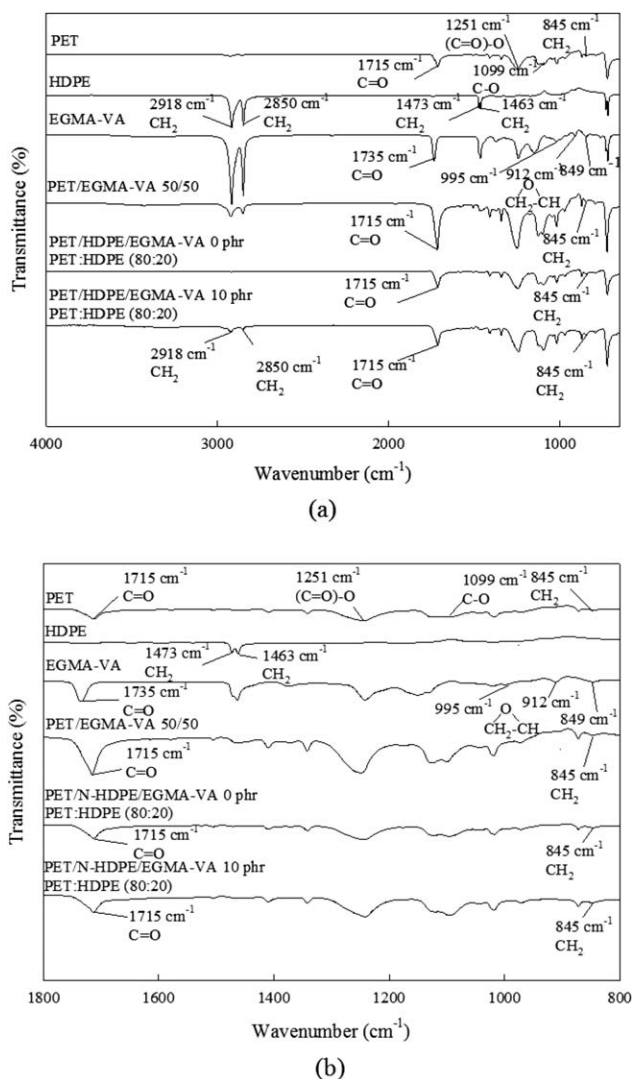


Figure 1. FT-IR spectra of PET/N-HDPE composites (a) Full region, (b) expanded region.

codes of PET : HDPE include 80/20, 60/40, 50/50, and 40/60. The compatibilizer was loaded at a composition of 10 phr (parts per hundred resins of PET and HDPE). For instance, the composition of compatibilized PET/N-HDPE composite at PET : HDPE of 80/20 ratio represent PET/HDPE/NIR/compatibilizer = 80/20/6.7/10. The detail formulation of the blends and composites is listed in Table I. The prepared samples were then hot-pressed at 250°C for 3 min to obtain thin sheets of about 1 mm.

Measurements

Structure Characterization. The Fourier transform-infrared spectra (FT-IR) to confirm the reaction between EGMA-VA and PLA was recorded using a spectrophotometer (Spectrum 100, Perkin-Elmer) at a resolution of 4 cm^{-1} for 32 scans from 650 to 4000 cm^{-1} . X-ray diffraction (XRD) techniques were employed to evaluate the crystalline structure.^{17,18} A Rigaku-Ultima IV X-ray unit (Cu-K α radiation), operating at 40 kV, 20 mA, was used for the experiments. The diffractograms were scanned in the 2θ range from 10° to 60° at a rate of 1.8°/min.

Morphological Characterization. The morphology of the cryo-fractured surface of specimens was elucidated with a scanning electron microscope (SEM) (TESCAN, 5136 MM), followed by extracting HDPE using para-xylene at 125°C for 10 hr.¹⁹ All samples were sputtered with gold before microscopic observations.

Thermal Characterization. The crystallization temperature (T_c), melting temperature (T_m), and crystallinity were determined using a differential scanning calorimetry (DSC) (DSC Q 10, TA). Crystallinity was calculated by taking the heat of fusion divided by the value of 117 J/g^{20} as the enthalpy of perfect crystal of PET, and 276 J/g^{20} as the enthalpy of perfect crystal of HDPE, respectively. The sample was first hold at 50°C for 1 min, and then heated to 270°C at 10°C/min to eliminate thermal history. After that, the sample was cooled down -70°C at 10°C/min, and then heated to 270°C again at 10°C/min. A dynamic mechanical analyzer (DMA) (Pyris Diamond, Perkin Elmer) was used to determine the glass transition temperatures based on the $\tan \delta$ of samples in a bending mode at a frequency of 1 Hz from -80 to 150°C at a heating rate of 5°C/min.

Mechanical Properties. Tensile measurements were conducted based on ASTM-D638 at a crosshead speed of 5 mm/min using an Instron 4469. Tensile strength, elongation at break, and Young's modulus were recorded.

Mixing Torque Properties. The equilibrium torque values of compounds mixed under 50 rpm at 250°C for 10 min were recorded.

Near Infrared Reflection. The reflection of near infrared range was elucidated with UV-vis near infrared spectrometer (LAMBDA, Perkin Elmer) on 2 mm thick specimen at the wavelength from 400 to 2400 nm.

RESULTS AND DISCUSSION

Structure Characterization

FT-IR spectra of typical PET/N-HDPE composites, neat resins, and compatibilizer are illustrated in Figure 1, including full region and expanded region. The characteristic functional groups for PET were at C=O (1715 cm^{-1}), (C=O)-O (1251 cm^{-1}), C-O (1099 cm^{-1}).^{21,22} The characteristic absorption peak regions of epoxy (849, 912, 995 cm^{-1}) and C=O (1735 cm^{-1}) for EGMA-VA were displayed as indicated in the literature.²³ For the PET/N-HDPE composites with the addition of the compatibilizer, most of typical absorption bands remained the same as those in neat PET as seen in the representative NIR-filled PET/HDPE (80/20) systems with or without compatibilizer. Therefore, the reaction between PET and EGMA-VA was not clearly discernible on the compatibilized composites. In order to confirm the reaction of carboxyl group on PET and epoxy group on the compatibilizer, PLA/EGMA-VA (50/50) blends were prepared. The epoxy peak assigned at 912 and 995 cm^{-1} disappeared and the carbonyl peaks at 1735 was slightly shifted after blending. This observation was attributed to the aforementioned reaction between the epoxy groups on EGMA-VA and terminal carboxylic acid and/or the terminal hydroxyl group on PET involved in the blends.²³ On top of that, the possible carbonyl group interactions between compatibilizer and

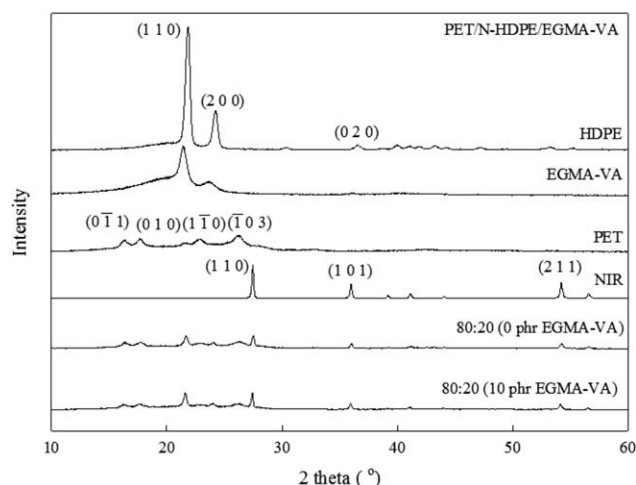


Figure 2. X-ray diffraction patterns from 10 to 60° of PET/N-HDPE composites.

polyester were also suggested to the observed carbonyl shift as disclosed in the literature.²⁴

Figure 2 shows the XRD patterns of neat PET, HDPE, and PET/N-HDPE composites (80/20) with or without compatibilizer. PET showed clear diffraction patterns at 16.4°, 17.7°, 22.8°, 26.2° for the corresponding crystal planes of (0 -1 1), (0 1 0), (1 -1 0), and (-1 0 3).²⁵ In addition, the characteristic diffraction peaks of 21.6° and 24° were corresponding to the HDPE

orthorhombic crystal plane (110) and (200), respectively, in combination with a broad amorphous halo.^{26,27} For PET/N-HDPE composites, the major diffraction peak remained unchanged, except for the observed NIR diffraction peaks at 27.4° (110), 36.0° (101), 54.2° (211), and the decreased intensity of diffraction peaks for PET with increasing HDPE contents (omitted for brevity). With the addition of EGMA-VA compatibilizer, the diffraction peak at 21.6° (110) intensified due to the synergistic contribution from HDPE and EGMA-VA, but the diffraction peak position remained largely unchanged, indicating the limited alternation of crystalline structure for the composite systems with or without compatibilizer.

Dispersion Assessment

Figure 3 shows the distinct morphology of cryogenic fractured specimens for unmodified and compatibilized PET/N-HDPE composites with xylene extraction to remove HDPE domain at various compositions. The images of samples without xylene treatment were omitted here for brevity. Figure 3(A) shows the micrographs of PET/N-HDPE/EGMA-VA 0 phr at different PET/HDPE ratio (a) 80/20 (b) 60/40 (c) 50/50. The 40/60 sample was not recovered for analysis because the sample (HDPE as a major component) was disintegrated during extracting process. Cavities with a dimension of a few μm in size representing HDPE domains appeared to turn into a co-continuous phase within PET. These observations indicated a lack of specific interaction between PET and N-HDPE. Further, with the

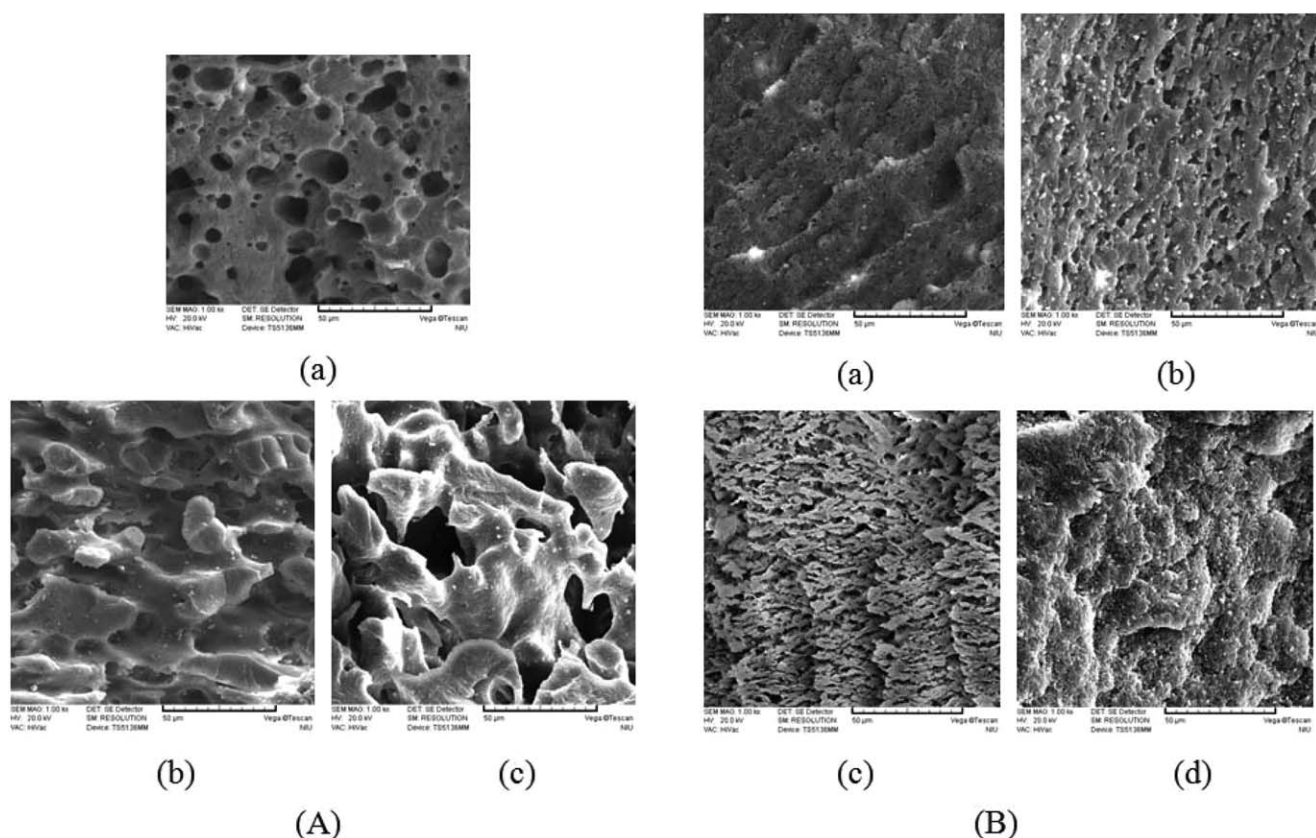


Figure 3. SEM micrographs of PET/N-HDPE composites with xylene extraction (A) without compatibilizer (a) 80/20, (b) 60/40, (c) 50/50, (B) with compatibilizer (a) 80/20, (b) 60/40, (c) 50/50, (d) 40/60 [scale bar: 50 μm].

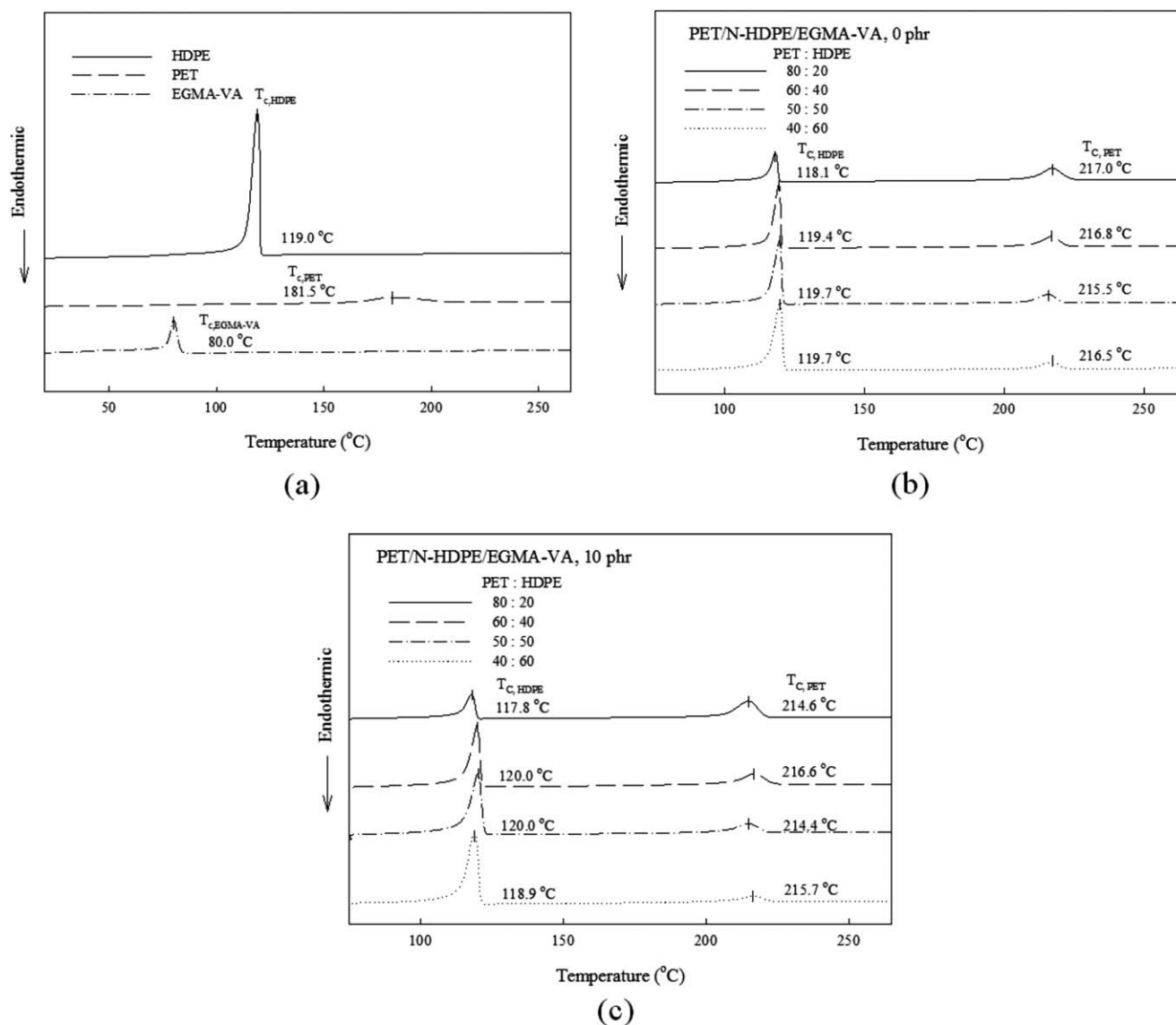


Figure 4. DSC thermographs of PET/N-HDPE composites under cooling condition (a) neat resins, (b) without compatibilizer, (c) with compatibilizer.

addition of EGMA-VA, the mean cavity sizes of HDPE substantially decreased for the representative 80/20 composition at 10 phr of compatibilizer as shown in Figure 3(B)—(a), suggesting a good interfacial bonding between PET matrix and HDPE dispersed phase with the help of compatibilizer. A similar observation for the enhanced interfacial interaction for the extracted morphology was elucidated in other compositions. In particular, 40/60 sample was still available for SEM analysis, signifying the effectiveness of the compatibilizer. Interestingly, when the extract liquid was under visual observation, the suspension clearly showed yellow color originated from NIR for PET/N-HDPE systems without compatibilizer, but the extract liquid was relatively clear for the compatibilized cases. This indicated that NIR was relocated from HDPE phase into PET phase with the help of the compatibilizer due to the hydrophilic nature of inorganic NIR for the compatibilized cases. Thus, NIR was also distributed within the PET matrix region for all investigated sys-

tems in various degrees, which should be kept in mind for the further discussion on the composite properties.

Thermal Characterization

The thermal behaviors of PET/N-HDPE composites with or without compatibilizer are depicted in Figure 4. The crystallization peak temperature values (T_c , temperature at the exotherm maximum) of PET, HDPE, and EGMA-VA were found to be about 181.5, 119, and 80.0°C, respectively. For the NIR-filled PET/HDPE composites at 80/20 composition without compatibilizer, as seen in Figure 4(b), the crystallization temperature of PET increased to 217.0°C. To better understand this nucleation role, control PET/NIR composites and PET/HDPE blends without NIR were carried out (curves omitted here for brevity). The amount of NIR was based on the assumption that NIR was completely located in the PET matrix. The highest increment in the crystallization temperature of PET was about 218.1°C

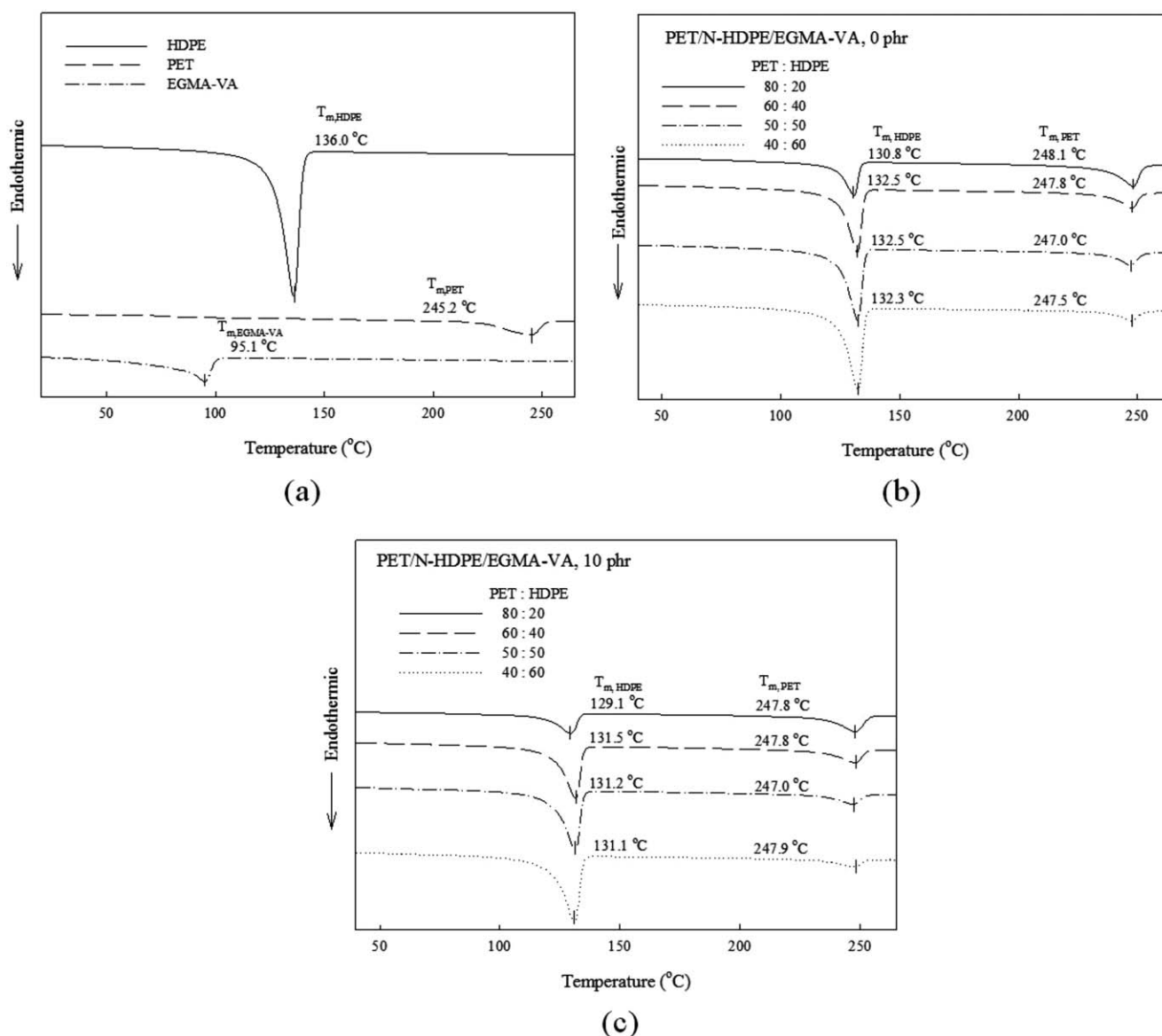


Figure 5. DSC thermographs of PET/N-HDPE composites under heating condition (a) neat resins, (b) without compatibilizer, (c) with compatibilizer.

corresponding to PET/NIR (40/20) derived from the PET/N-HDPE composites at PET/HDPE = 40/60 composition containing NIR for a fixed ratio of HDPE/NIR (3/1). Yet, for control PET/HDPE blends without any NIR, the crystallization temperatures of PET also increased up to 216.3°C regardless of the HDPE content. The nucleation role of HDPE for their PET/HDPE (30/70) blends was also suggested by Torres et al.²⁸ Thus, the observed T_c increment in PET for the investigated PET/N-HDPE composites was mainly due to the nucleation role of both inorganic NIR and HDPE, as seen in the control PET/NIR composites and PET/HDPE blends without NIR. On the other hand, the crystallization temperature of HDPE remained largely unchanged due to its fast crystallization rate. A similar finding was also reached for the other PET/N-HDPE compositions, except for the variation of respective peak intensity corresponding to different compositions.

With the addition of compatibilizer into the PET/N-HDPE composites, it was thought that the enhanced compatibility between PET and EGMA-VA would suppress the crystallization rate of PET. However, Figure 4(c) shows very limited decrement within a few degrees in the crystallization temperatures of PET in comparison with those without compatibilizer.

To further investigate the melting behaviors of the composites, Figure 5(a) illustrates the melting temperatures for each component. For the NIR-filled PET/HDPE composites at PET : HDPE (80/20) composition without compatibilizer, the melting temperature of HDPE was slightly shifted from 136.0°C to 130.8°C stemming from the disruption of crystalline domains due to the existence of NIR. No much NIR effect on the melting temperatures of PET was observed. A similar observation was also found for the other PET/N-

Table II. Crystallinity of PET/N-HDPE/EGMA-VA

Sample code	PET/HDPE (wt %/wt %)	X_c , PET (%)	X_c , HDPE (%)
PET	100/0	38	-
HDPE	0/100	-	63.4
	80/20	33.8	57.8
PET/N-HDPE/ EGMA-VA 0 phr	60/40	31.5	60.5
	50/50	29.5	58.2
	40/60	27.9	59.1
	80/20	31.2	53.3
PET/N-HDPE/ EGMA- VA10 phr	60/40	30.7	58.0
	50/50	28.1	56.2
	40/60	25.0	55.4

HDPE compositions, except for the variation of respective peak intensity corresponding to different compositions. Additionally, the effect of compatibilizer on the melting behaviors of composites at various PET/N-HDPE compositions was marginal as well. A similar trend was also observed on the crystallinity as listed in Table II. Basically, the addition of N-HDPE and compatibilizer slightly decreased the crystallinity of neat HDPE and PET. The effect of compatibilizer on the composites was limited in considering the broad peak in the DSC traces. Thus, the later discussion on the mechanical properties would mainly attribute to the enhanced compatibility between PET and N-HDPE rather than the structure variation from the crystalline effect of PET or HDPE.

Dynamic Mechanical Behaviors

The $\tan \delta$ peak maximum as an index of glass transition temperature or melting temperature for PET/N-HDPE composites with or without compatibilizer at various HDPE contents is shown in Figure 6(a,b). It was found that the glass transition temperatures (corresponding to α relaxation), about 90°C, of PET in the PET/N-HDPE systems without compatibilizer did not vary with the N-HDPE compositions. A similar situation was found for the secondary relaxation process, denoted as β , and appeared as a weak and broad maximum of $\tan \delta$ near -63°C for PET.²⁹ This suggests the segmental motion of PET was not limited by the incorporated NIR or EGMA-VA. The melting peak intensities of HDPE tended to increase with increasing their contents, but the values of melting temperatures remained largely similar in considering the experimental error involved when HDPE portion began to flow. Also, an increasing intensity of the broad shoulder above 30°C associated to the slippage of crystalline polyethylene region was observed with increasing HDPE contents. A similar situation was observed for the corresponding systems with the compatibilizer.

Mechanical Properties

Although the performance of NIR was often demanded for the conventional roof application, there are some potential applications, such as textile materials and greenhouse films,^{14,15} where the basic mechanical properties are required besides the enhanced reflective properties. Figure 7 shows the effect of compatibilizer on tensile strength, elongation at break, and Young's modulus of PET/N-HDPE composites. With increasing N-HDPE content, tensile strength, as seen in Figure 7(a), decreased slightly regardless of the use of the compatibilizer mainly due to the relatively soft nature of HDPE with less loading capacity in comparison with PET. Note that NIR was also distributed into PET as mentioned earlier in the SEM analysis. A control test of PET/NIR was carried out to observe their effect on the mechanical properties by assuming all NIR were located in PET phase. For instance, NIR-filled PET/N-HDPE system at the PET : HDPE (80/20) composition corresponds to PET/NIR (80/6.7) at a fixed weight ratio of HDPE/NIR (3/1). It showed a reinforcing effect on the tensile strength of 14.1 ± 0.3 MPa for the representative PET/NIR (80/6.7) system without HDPE in comparison with neat PET at 8.4 ± 0.9 MPa. Thus,

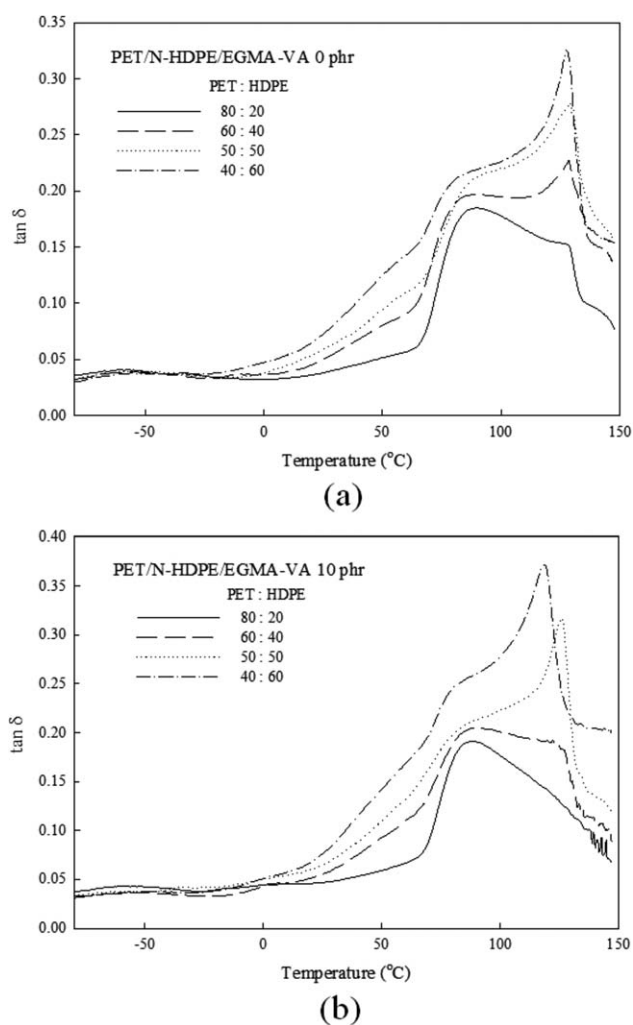


Figure 6. $\tan \delta$ of PET/N-HDPE composites (a) without compatibilizer, (b) with compatibilizer.

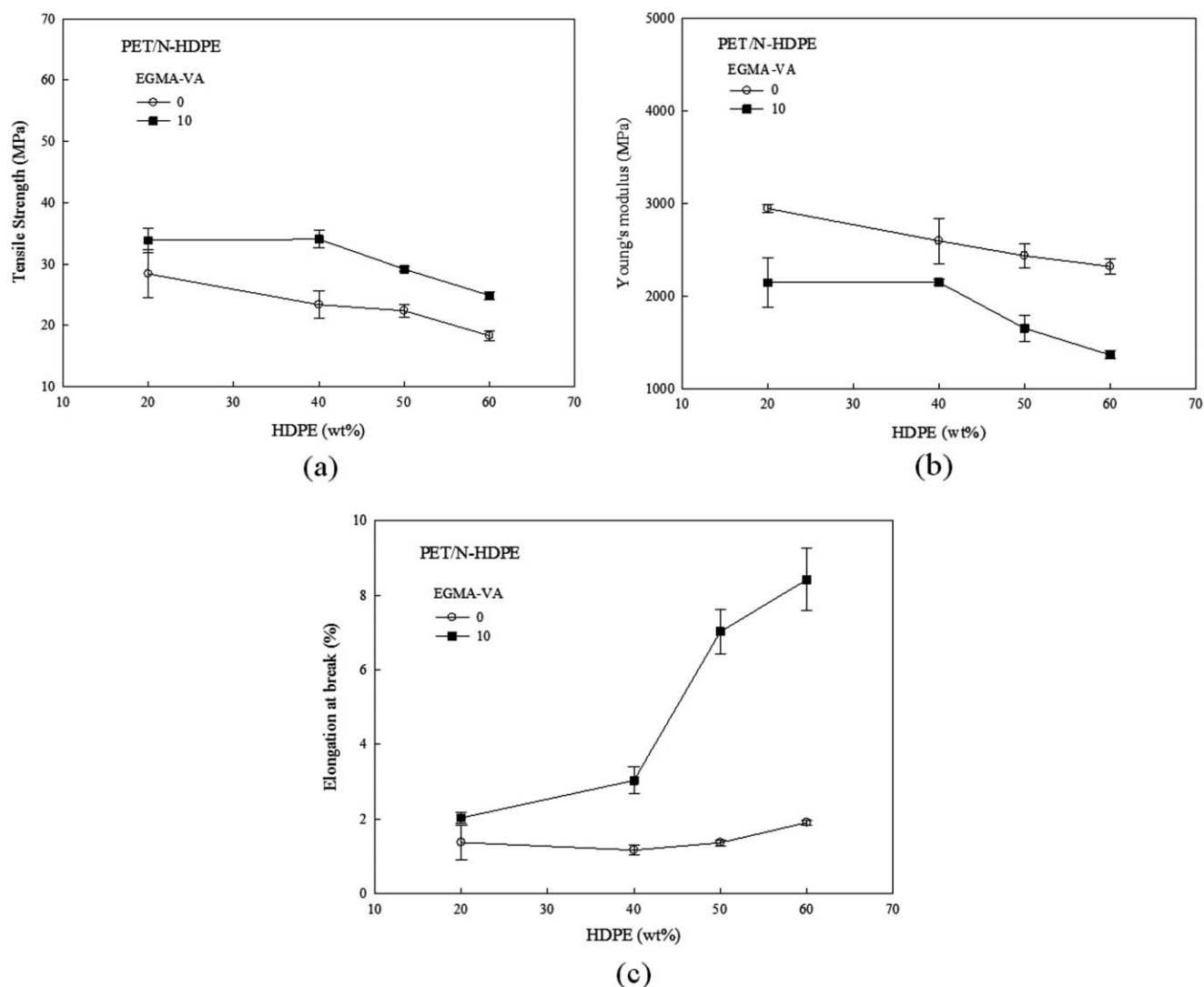


Figure 7. Tensile properties of PET/N-HDPE composites (a) tensile strength, (b) Young's modulus, (c) elongation at break.

the dominating effect of HDPE content over NIR was recognized. In addition, tensile strength for compatibilized cases at various N-HDPE contents conferred higher values than that for the corresponding counterparts without compatibilizer. Apparently, the interfacial interaction between PET and EGMA-VA compatibilizer was essential for the observed phenomenon.

To get more understanding on the tensile properties of PET/N-HDPE composites, Young's modulus is illustrated at various N-HDPE contents as shown in Figure 7(b). With increasing N-HDPE content, Young's modulus decreased as seen in tensile strength mainly due to the increased content of HDPE with relatively soft nature in comparison with PET. Note that the rigidity from NIR did not outperform soft HDPE, as the HDPE content dominated the inorganic NIR content at the ratio of 3/1, which was also mentioned previously in the control study of PET/NIR system regarding tensile strength. Interestingly, Young's modulus decreased about 27% at NIR-filled PET/N-HDPE system at the PET : HDPE (80/20) composition

upon adding compatibilizer. A similar observation was found for other N-HDPE compositions. This was attributed to the rubbery nature of EGMA-VA at a low glass transition temperature of -15°C . Thus, even though the enhanced compatibility between PET and EGMA-VA was attained, Young's modulus of compatibilized systems was about 40% lower than that of systems without compatibilizer. Note that earlier discussion on the structure variation from the crystalline effect of PET or HDPE was limited, thus the observed results would mainly attribute to the enhanced compatibility between PET and N-HDPE.

For the elongation at break, a significant increment for the PET/N-HDPE composites containing compatibilizer due to a higher content of HDPE and soft EGMA-VA was observed. This increment was not so noteworthy without the addition of compatibilizer. Apparently, the interfacial interaction between PET and EGMA-VA compatibilizer was essential for the observed phenomenon. Overall, compatibility and compatibilizer properties were

Table III. The Mixing Torques of PET/N-HDPE/EGMA-VA

Sample code	EGMA-VA	PET/HDPE	Torque (Nm)
PET	-	-	3.5
HDPE	-	-	27.9
N-HDPE	-	-	18.6
EGMA-VA	-	-	5.6
PET/EGMA-VA	10 phr	-	9.8
		80 : 20	6.0
	0 phr	60 : 40	8.6
		50 : 50	10.4
PET/N-HDPE/ EGMA-VA		40 : 60	13.2
		80 : 20	15.2
		60 : 40	19.6
		50 : 50	25.0
	10 phr	40 : 60	28.5

major factors in attaining the best performance of PET/N-HDPE composites.

Mixing Torque Properties

A brabender mixer torque was used to get some understanding of the interfacial interaction between PET and N-HDPE in terms of processing point of view, the equilibrium torque values for PET/N-HDPE composites with or without compatibilizer is shown in Table III. The torque values of control samples like PET and EGMA-VA were about 3.5 Nm and 5.6 Nm, respectively. To investigate the interaction between PET and EGMA-VA, 10 phr of EGMA-VA was blended with PET for a demonstration. The torque value of PET/EGMA-VA blend was about 9.8 Nm, which was higher than that of each individual component. The result indicated that the possible formation of PET-co-EGMA-VA copolymer in agreement with previous FTIR and SEM analyses, leading to the increment of mixing torques. For the PET/N-HDPE systems, the torque values increased with increasing N-HDPE content due to the incorporated filler and high viscosity of HDPE. With the incorporation of compatibilizer, the torque values increased more than twofold for each NIR-filled HDPE composition, which was attributed to the enhanced interfacial interaction through the formation of PET-co-EGMA-VA copolymer as mentioned earlier. Note that this torque increment of compatibilized blends was not attributed to the contribution of EGMA-VA compatibilizer, as its value was still lower than that of neat HDPE. Overall, the processing characteristic could be a useful tool to evaluate the interaction degree between PET and N-HDPE through the help of compatibilizer.

Near Infrared Reflection

To have a thorough understanding on the incorporated functional pigments on the effect of reflection properties in their near infrared range, the reflection properties were determined, as illustrated in Figure 8. Generally, high reflectance

values indicate that the less thermal effect due to the anti-reflection of near IR radiation was expected. For unfilled neat PET, the reflectance was about in the lowest value in the investigated ranges above 1000 nm. With the inclusion of NIR into HDPE to form PET/N-HDPE composites with or without EGMA-VA compatibilizer, the values of reflectance increased to a great degree as seen in Figure 8(b) for a representative comparison at 1500 nm. In addition, the values slightly increased with increasing N-HDPE content especially at the higher wavelength range, revealing that the incorporated NIR was advantageous to improve the reflection properties of prepared composite systems. Although, the effectiveness of compatibilizer did not seem to have much effect on the reflection properties for the investigated systems at various N-HDPE contents, the application of compatibilizer was still quite feasible to improve the mechanical properties for the NIR reflective composites in the melt blending approach. This improvement would be helpful in some potential applications where the mechanical properties are also desirable besides the demand on the NIR reflectivity.

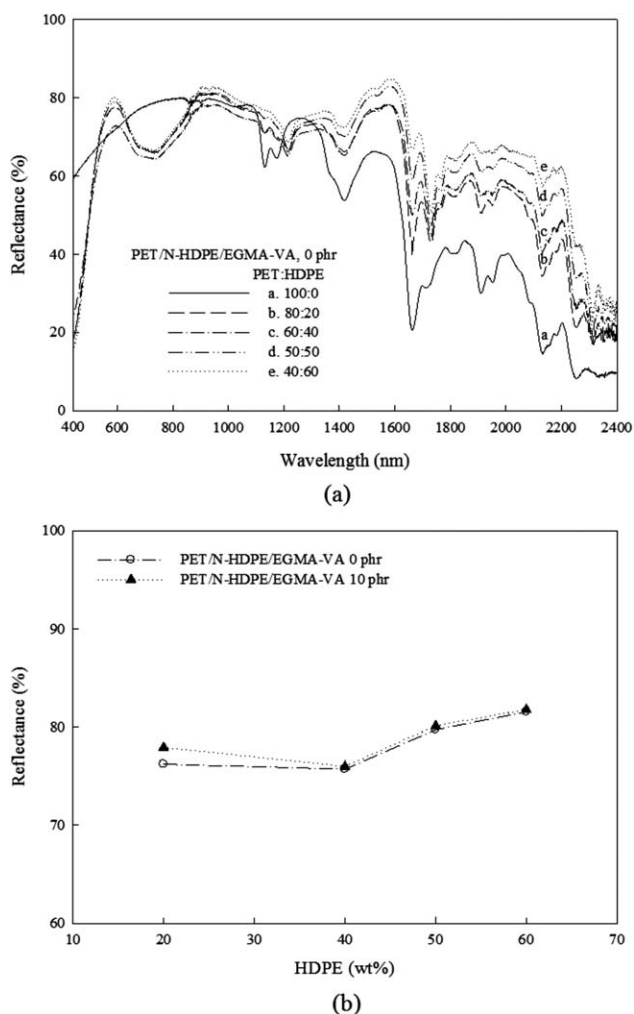


Figure 8. UV-Vis reflection curves of PET/N-HDPE composites (a) without compatibilizer, (b) representative comparison at 1500 nm.

CONCLUSION

This work aims to assess the addition of NIR effect on the NIR dispersion, thermal properties, mechanical properties, and reflection properties to contrast the significance of compatibilizer and NIR modification in the PET/HDPE/NIR blends and composites. FT-IR confirmed the reaction between the epoxy groups on EGMA-VA and terminal carboxylic acid and/or the terminal hydroxyl group on PET involved in the blends, leading to good compatibility between PET and N-HDPE in agreement with SEM and mixing torque evaluation. The limited alternation of crystalline structure for the composite systems with or without compatibilizer was found through XRD and thermal analyses. The observed T_c increment in PET for the investigated PET/N-HDPE composites was mainly due to the nucleation role of both inorganic NIR and HDPE, but no much effect from the addition of compatibilizer. Tensile strength and elongation at break for compatibilized cases at various N-HDPE contents conferred higher values than that for the corresponding counterparts without compatibilizer, attributed to the rubbery nature of EGMA-VA. Thus, even though the enhanced compatibility between PET and EGMA-VA was attained, Young's modulus for compatibilized systems was about 40% lower than that for systems without compatibilizer. Apparently, compatibility and compatibilizer properties were major factors in attaining the best performance of PET/N-HDPE composites. With the incorporation of compatibilizer, EGMA-VA, the torque values increased more than twofold for each filled N-HDPE composition, which was attributed to the enhanced interfacial interaction through the formation of PET-co-EGMA-VA copolymer. With the inclusion of NIR into HDPE to form PET/N-HDPE composites with or without EGMA-VA compatibilizer, the values of reflectance increased to a great degree. Although, the effectiveness of compatibilizer did not seem to have much effect on the reflection properties for the investigated systems at various N-HDPE contents, the application of compatibilizer was still quite feasible to improve the mechanical properties for the NIR reflective composites in the melt blending approach. In particular, there are some potential applications, such as textile materials and greenhouse films, where the basic mechanical properties are required besides the enhanced reflective properties.

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