

# Effect of Zeolite 5A on Compatibility and Properties of Linear Low-Density Polyethylene/Thermoplastic Starch Blend

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**ABSTRACT:** Polymer composites consisting of linear low-density polyethylene (LLDPE), thermoplastic starch (TPS), and zeolite 5A (Z), with a constant PE to TPS weight ratio of 70 : 30 and zeolite 5A contents of 1–5 wt % were prepared in the forms of pellets and films by using a co-rotating intermeshing twin-screw extruder and a blown film extrusion line, respectively. The objective of this work was to investigate the effect of zeolite 5A on compatibility between PE and TPS, as well as morphological, thermal, and tensile properties of PE/TPS/Z composites. The presence of zeolite 5A increased the miscibility and tensile properties of the PE/TPS blend. Tensile properties of the blend considerably improved after compounding with zeo-

lite 5A, as the tensile strength, modulus, and elongation at break increased significantly ( $P \leq 0.05$ ) by up to ~ 60, 30, and 70%, respectively. Increasing the zeolite 5A content from 1–5 wt % significantly increased ( $P \leq 0.05$ ) the tensile strength, modulus, and elongation at break of PE/TPS/Z composites from ~ 12 to 16 MPa, 133 to 154 MPa, and 305 to 390%, respectively. However, the addition of zeolite 5A slightly decreased the thermal stability of the PE/TPS blend by ~ 5–15°C. © 2012 Wiley Periodicals, Inc. *J Appl Polym Sci* 000: 000–000, 2012

**Key words:** linear low-density polyethylene; thermoplastic starch; zeolite 5A; composites; compatibility

## INTRODUCTION

Polyethylene (PE), a thermoplastic polymer, is extensively used in various applications including packaging and agricultural films due to its high flexibility and seal strength as well as easy processability.<sup>1</sup> However, after usage the discarded polymer contributes to environmental pollution. Consequently, there has been increasing interest in reducing the use of PE by blending with a cheap biodegradable polymer, especially starch due to its abundance and renewability.

Starch is a semicrystalline polymer composed of linear amylose (poly- $\alpha$ -1,4-D-glucopyranoside) and branched amylopectin (poly- $\alpha$ -1,4-D-glucopyranoside and  $\alpha$ -1,6-D-glucopyranoside).<sup>2,3</sup> Inclusion of starch granules enhances the biodegradability of PE<sup>4</sup> but the obtained starch-filled polymer has poor compatibility and mechanical properties. In native form, starch granules have limited processability due to the strong inter- and intramolecular hydrogen bonds between the starch molecules restricting the molecular mobility. Consequently, native starch cannot be thermally processed as a thermoplastic material.<sup>5</sup> Introduction of a plasticizer such as glycerol<sup>2,5</sup> or sorbitol<sup>6</sup> under heating and high shear improves the movement of starch molecules and provides plasticized starch, the so-called thermoplastic starch (TPS). Nevertheless, TPS still has limited applications due to its moisture sensitivity, poor thermal resistance, and low strength and resilience.<sup>7</sup> Several attempts have focused on enhancing these drawbacks by melt blending TPS with a hydrophobic and flexible polymer such as PE.<sup>8,9</sup> However, melt blending of these two polymers often results in immiscible blends due to the high interfacial tension between the nonpolar PE and the highly polar TPS.<sup>10</sup> To

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overcome this problem, several alternatives have been investigated, including: (i) chemically modifying starch<sup>11,12</sup> and PE<sup>1,13–15</sup> and (ii) incorporating chemical compatibilizers into the PE/TPS blend.<sup>9</sup> Sailaja<sup>12</sup> and Bikiaris and Panayiotou<sup>13</sup> reported that introduction of poly(ethylene-*co*-glycidyl methacrylate) and poly(ethylene-*grafted*-maleic anhydride) improved the miscibility between PE and TPS. However, if too high concentration of a copolymer is used as a compatibilizer in polymer blends, it could form a distinct phase and no longer contribute to the compatibilization.<sup>16</sup> In addition, chemical modifications and compatibilizer syntheses are relatively expensive, complicated, and time-consuming. Alternatively, nano/micro inorganic fillers such as organoclay and zeolite could be used to improve the miscibility of polymer blends, in addition to enhancing the mechanical properties of polymers<sup>17,18</sup> and polymer blends.<sup>19–21</sup> Several studies have reported the compatibilizing effect of organoclay in polymer blends<sup>20–22</sup>; however, thus far only Djoumaliisky and Zipper<sup>19</sup> have reported on the compatibilizing effect of an activated natural zeolite in a recycled polymer blend.

Zeolites are nanoporous crystalline aluminosilicate materials, with pore sizes ranging from  $\sim 3$  to 15 Å.<sup>18</sup> The structures of zeolites comprise three-dimensional frameworks of SiO<sub>4</sub> and AlO<sub>4</sub> tetrahedra. Because of their porosity and ability to selectively adsorb or refuse specific molecules, zeolites have been widely used as absorbents for separation and purification of gases and liquids.<sup>23,24</sup> In addition, zeolites are also used as a filler to improve the physical and mechanical properties of polymers (e.g., linear low-density polyethylene (LLDPE) and polylactic acid)<sup>18,25</sup> and a recycled polymer blend (consisting of polypropylene, low- and high-density PE, and polystyrene).<sup>19</sup> Biswas et al.<sup>25</sup> reported that increasing zeolite 4A content up to 50 wt % increased the Young's modulus and yield stress of LLDPE from 127 to 179 MPa and 9.4 to 11.1 MPa, respectively. Yuzay et al.<sup>18</sup> also reported that increasing zeolite 4A concentration up to 5 wt % resulted in increased Young's modulus of polylactic acid from 1295 to 1465 MPa and tensile strength from 62.5 to 67.6 MPa, but with a slightly decreased elongation at break from 6.9 to 6.6%. Furthermore, Djoumaliisky and Zipper<sup>19</sup> reported that an activated natural zeolite had a compatibilizing effect on a recycled tetra-component polymer blend consisting of polypropylene (40 wt %), low- and high-density PE (15 and 40 wt %, respectively), and polystyrene (5 wt %). Compounding this polymer blend with the zeolite yielded increased Young's modulus, while elongation at break decreased. When the zeolite content was increased up to 20 wt %, Young's modulus of the polymer blend increased from 212 to 290 MPa, whereas its elongation at break decreased from 12.6

to 5.7%. However, enhanced flowability of the composites and improved compatibility of the polymer blend were obtained only at low concentrations of zeolite (1–2 wt %).

Accordingly, it remains challenging to use zeolite to improve the miscibility between PE and TPS. The aim of present work was to study the compatibilizing effect of zeolite 5A in a PE/TPS blend. Zeolite 5A was used in this work, since as yet there have been no reports on the compatibilizing effect of this material. In this article, we report on the effect of zeolite 5A concentration on morphological, thermal, and mechanical properties of PE/TPS/zeolite 5A composites.

## EXPERIMENTAL

### Materials

LLDPE (grade LL7410D) with density of 0.921 g/cm<sup>3</sup> and melt-flow index (MFI) of 0.98 g/10 min (190°C, load 2.16 kg) was purchased from PTT Polymer Marketing (Thailand). Cassava starch (13.2% inherent moisture) was obtained from Tong Chan (Thailand). Zeolite 5A (Z) with pore size of 4–5 Å was received as a gift from Thai Silicate Chemicals (Thailand). Glycerol (99.5% purity) was purchased from Siam Chemicals Solutions (Thailand). All materials and chemicals were used as received.

### Preparation of thermoplastic starch

Cassava starch and glycerol with a starch to glycerol weight ratio of 100 : 27 were mixed for 30 min using a 20-L mixer (Mitsubishi, Japan). The mixture was then extruded using a co-rotating, fully intermeshing twin-screw extruder (LTE-20–40, Labtech Engineering, Thailand) with a screw diameter of 20 mm and a screw length to diameter ( $L/D$ ) ratio of 40 : 1. Extrusion was carried out at a temperature range of 80–160°C and a screw speed of 175 rpm. The extrudate was cut into 2.5-mm length pellets by a pelletizer (LZ-120, Labtech Engineering). The obtained TPS pellets were dried in a hot-air oven at 50°C overnight and then stored in a desiccator at ambient temperature.

### Preparation of PE/TPS/Z composites

Prior to extrusion, LLDPE and zeolite 5A were dried in a hot-air oven at 60°C (24 h) and 130°C (3 h), respectively. PE/TPS/Z composites were prepared by a two-step process. In the first step, PE was melt compounded with zeolite 5A at concentrations of 1.43, 4.29, and 7.14 wt % using the same twin-screw extruder, with processing temperatures ranging from 90 to 150°C and a screw speed of 180 rpm. The extrudate was cut into 2.5-mm length pellets by a

**TABLE I**  
**Samples and Constituents**

Samples	LLDPE (wt %)	TPS (wt %)	Zeolite 5A (wt %)
PE	100	—	—
TPS	—	100	—
PE/TPS	70	30	—
PE/TPS/Z1	69.3	29.7	1
PE/TPS/Z3	67.9	29.1	3
PE/TPS/Z5	66.5	28.5	5

pelletizer. The prepared PE/Z composites were then melt blended with the previously obtained TPS, with a constant weight ratio of PE to TPS of 70 : 30, using the same twin-screw extruder in order to produce PE/TPS/Z composites with zeolite 5A concentrations of 1, 3, and 5 wt %. Extrusion was performed at a temperature range of 80–140°C and a screw speed of 180 rpm. The extrudate was cut into 2.5-mm length pellets by a pelletizer. The obtained PE/TPS/Z composites were dried in a hot-air oven at 60°C overnight and then stored in a desiccator at ambient temperature.

#### Film blowing of PE/TPS/Z composites

PE/TPS/Z composite pellets were converted into films by blown film extrusion using a single-screw extruder (LE25-30/C, Labtech Engineering), with a screw diameter of 25 mm and an  $L/D$  ratio of 30 : 1, equipped with a film-blowing attachment (LF-400, Labtech Engineering). Blown film extrusion was carried out at a temperature range of 170–180°C, a screw speed of 45 rpm, a blow-up ratio of 3 : 1, and a take-off speed of 4.5 m/min. The obtained film thickness and lay-flat width were  $0.040 \pm 0.003$  mm and  $150 \pm 11.38$  mm, respectively. The detailed constituents of the samples are listed in Table I.

#### Characterization

##### Scanning electron microscopy

Extrudate strands of PE/TPS/Z composites were fractured after freezing in liquid nitrogen, and the exposed surfaces were observed with a field emission scanning electron microscope (FESEM) (Hitachi S-4700, Japan) with an accelerating voltage of 3 kV. All the specimens were mounted on aluminum stubs using double-sided adhesive carbon tape and sputter-coated with gold prior to characterization.

##### X-ray diffraction

The crystallinity of PE/TPS/Z composites was characterized using an X-ray diffractometer (XRD) (X'Pert Powder, PANalytical B.V, The Netherlands), with Cu

$K\alpha$  radiation ( $\lambda = 0.1543$  nm) operating with an accelerating voltage of 40 kV and a current of 30 mA. All the samples were scanned by plates over a  $2\theta$  range of 5°–40° using a scan rate of 0.03°/sec.

##### Fourier transform infrared spectroscopy

Fourier transform infrared (FTIR) analysis of PE/TPS/Z composite films was performed in the transmission mode using a Bruker spectrometer (Tensor 27, Bruker Optics, Billerica, MA) over a wavenumber range of 4000–400  $\text{cm}^{-1}$  with 32 scans at a resolution of 4  $\text{cm}^{-1}$ .

##### Thermal analysis

Thermal transitions (i.e., glass transition and melting) of PE/TPS/Z composite films were determined using a differential scanning calorimeter (DSC) (DSC1 STAR<sup>e</sup>, Mettler Toledo, Switzerland) by heating from –60 to 300°C at a rate of 10 °C/min and then cooling back down to –60°C at a rate of 20 °C/min under a nitrogen atmosphere with a gas flow rate of 50 mL/min. Thermal decomposition of PE/TPS/Z composite films was investigated using a thermogravimetric analyzer (TGA) (TGA/DSC1 STAR<sup>e</sup>, Mettler Toledo) at temperatures ranging from 30 to 600°C with a heating rate of 20 °C/min under a nitrogen atmosphere with a gas flow rate of 50 mL/min.

##### Tensile testing

Tensile strength, Young's modulus, and elongation at break of PE/TPS/Z composite films were measured using an electronic tensile strength meter (5965, Instron, UK) equipped with a 5 kN load cell, according to the ASTM D882-02 method, with a crosshead speed of 50 mm/min and a gauge length of 50 mm. Prior to tensile measurements, the samples were stored in a closed chamber containing a saturated aqueous solution of sodium nitrite at 25°C (65% RH) for 48 h.

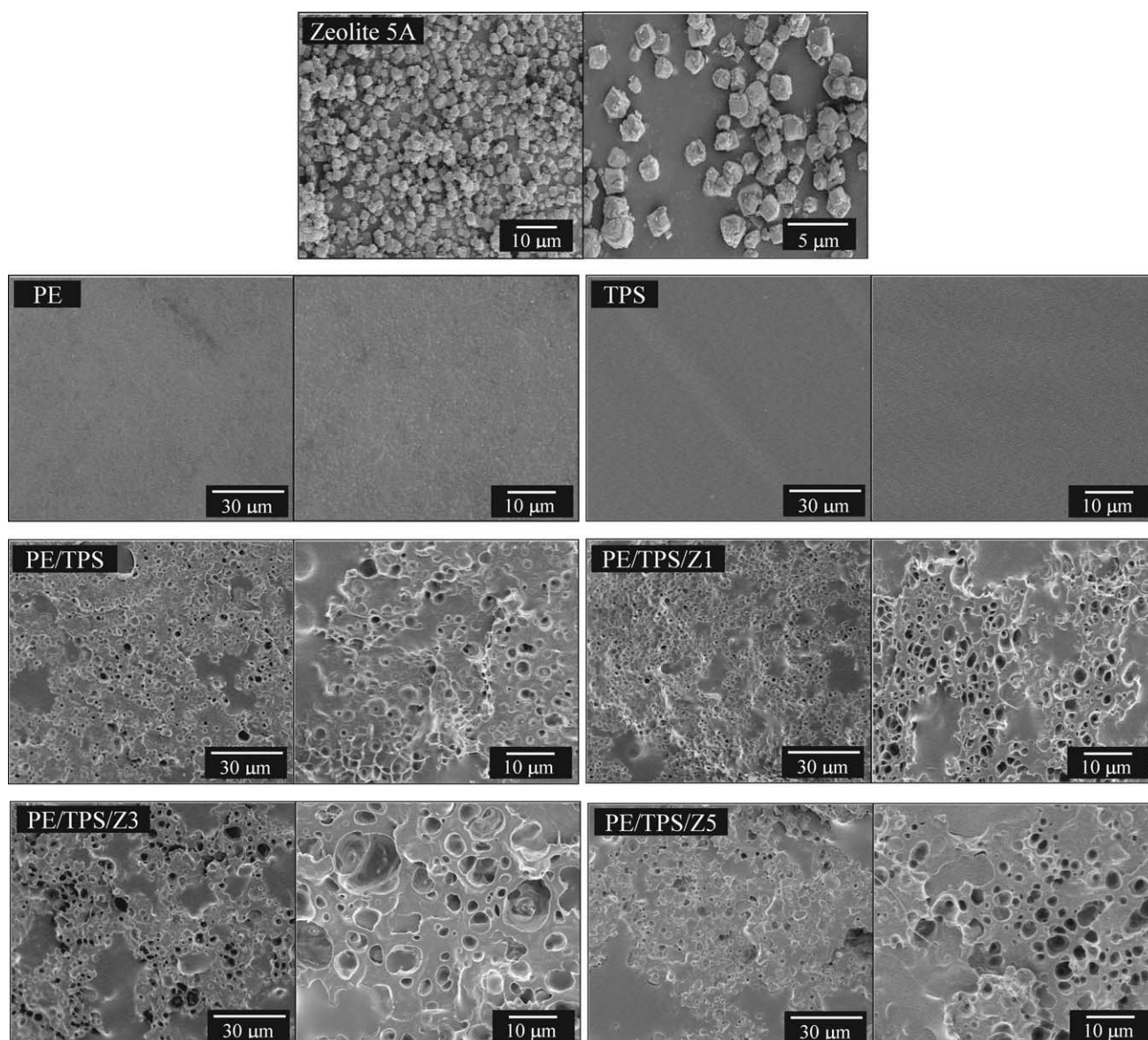
##### Statistical analysis

Data obtained from DSC and tensile measurements were subjected to one-way analysis of variance (ANOVA) using SPSS Statistics version 10.0. The statistical significance of difference between mean values was determined using the Duncan's new multiple-range test at  $P \leq 0.05$ .

## RESULTS AND DISCUSSION

### Microstructure of PE/TPS/Z composites

SEM micrographs of zeolite 5A and fracture surfaces of PE, TPS, PE/TPS blend, and PE/TPS/Z composites are illustrated in Figure 1. Zeolite 5A particles

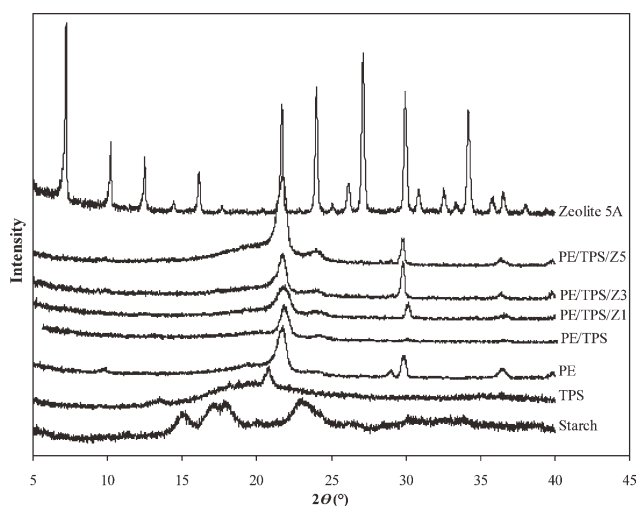


**Figure 1** SEM micrographs of zeolite 5A particles and fractured surfaces of PE, TPS, PE/TPS blend, and PE/TPS/Z composites.

exhibited a cubical shape with particle size of  $\sim 2.5$ – $3.0 \mu\text{m}$ . Both PE and TPS surfaces were smooth and homogeneous. After melt blending PE with TPS at a weight ratio of 70 : 30, the obtained blend was immiscible due to the hydrophobic and hydrophilic natures of PE of TPS, respectively, resulting in the formation of PE continuous phase and TPS dispersed phase.<sup>9</sup> This phase separation was possibly due to the poor interfacial adhesion between PE and TPS. Introduction of zeolite 5A (1–5 wt %) into the PE/TPS blend resulted in PE/TPS/Z composites with zeolite 5A being dispersed in both dispersed and continuous phases. The domains of the dispersed phase of the blend became smaller after incorporating 1 wt % of zeolite 5A (PE/TPS/Z1), indicating improved miscibility between PE and

TPS. Furthermore, the continuous phase region became enlarged with increasing zeolite 5A concentration. Therefore, the results suggest that introduction of zeolite 5A promotes the compatibility between PE and TPS. A similar compatibilizing effect was also reported when organically modified montmorillonite was used as a filler in poly(L-lactide)/poly( $\epsilon$ -caprolactone) and polypropylene/poly-styrene blends.<sup>20,22</sup>

Figure 2 shows XRD patterns of PE/TPS/Z composites in comparison with those of cassava starch, zeolite 5A, PE, TPS, and PE/TPS blend. Cassava starch exhibited characteristic peaks at  $2\theta$  of  $15.2$ ,  $17.2$ ,  $18.1$ , and  $22.8^\circ$ , corresponding to an A-type crystal structure.<sup>26,27</sup> After plasticizing with glycerol, the A-type crystallinity disappeared and  $V_A$ -type



**Figure 2** X-ray diffraction patterns of cassava starch, zeolite 5A, PE, TPS, PE/TPS blend, and PE/TPS/Z composites.

crystallinity was formed in TPS with new peaks at  $2\theta$  of  $13.5^\circ$  and  $20.7^\circ$ . This indicates the complete destruction of A-type crystalline structure of native starch granules and the formation of  $V_A$ -type crystalline structure by amylose complexed with glycerol or lipids in TPS.<sup>28–30</sup> When TPS was melt blended with PE at a TPS to PE weight ratio of 30 : 70, the diffraction peak of TPS at  $2\theta$  of  $13.5^\circ$  was hidden by the PE amorphous domain, the peak of TPS at  $20.7^\circ$  overlapped with the peak of the PE crystalline domain, and the original main characteristic peak of PE at  $2\theta$  of  $21.8^\circ$  became broader and less intense.<sup>31</sup> After incorporating 1–5 wt % of zeolite 5A into the PE/TPS blend, the main characteristic peaks of the PE/TPS blend still existed, and no characteristic peaks of zeolite 5A at  $2\theta$  of  $7, 10, 24, 31,$  and  $34^\circ$  were observed, possibly because of the very small amount of zeolite 5A present in the PE/TPS/Z composites. In addition, the trend of increasing crystallinity of PE/TPS/Z composites with zeolite 5A content was observed in Figure 2, in agreement with that of polylactic acid/zeolite 4A composites previously reported by Yuzay et al.<sup>18</sup>

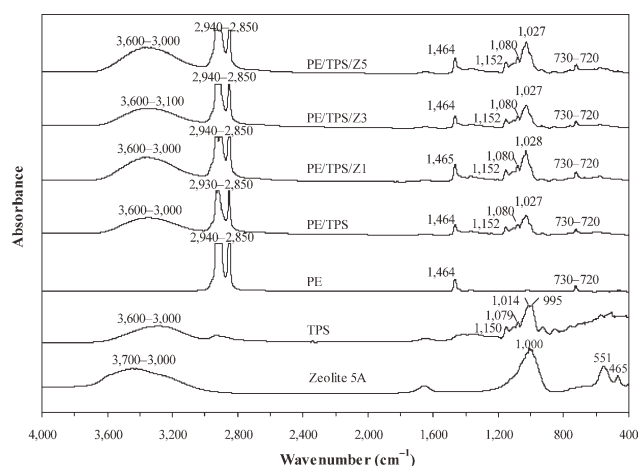
### FTIR analysis of PE/TPS/Z composites

FTIR spectra of PE/TPS/Z composites in a wavenumber range of  $4000\text{--}400\text{ cm}^{-1}$  are shown in comparison with those of zeolite 5A, TPS, PE, and PE/TPS blend (Fig. 3). Characteristic peaks of zeolite 5A occurred at wavenumbers of  $465\text{ cm}^{-1}$  (Si–O–Al bending),  $551\text{ cm}^{-1}$  (tetrahedron ring),  $1000\text{ cm}^{-1}$  (Si–O and Al–O asymmetric stretching), and  $3700\text{--}3000\text{ cm}^{-1}$  (O–H stretching).<sup>32</sup> TPS showed main peaks at  $995$  and  $1014\text{ cm}^{-1}$  (C–O stretching of C–O–C in the anhydroglucose ring),  $1079$  and  $1150\text{ cm}^{-1}$  (C–O stretching of C–O–H), and  $3600\text{--}3100\text{ cm}^{-1}$  (O–H

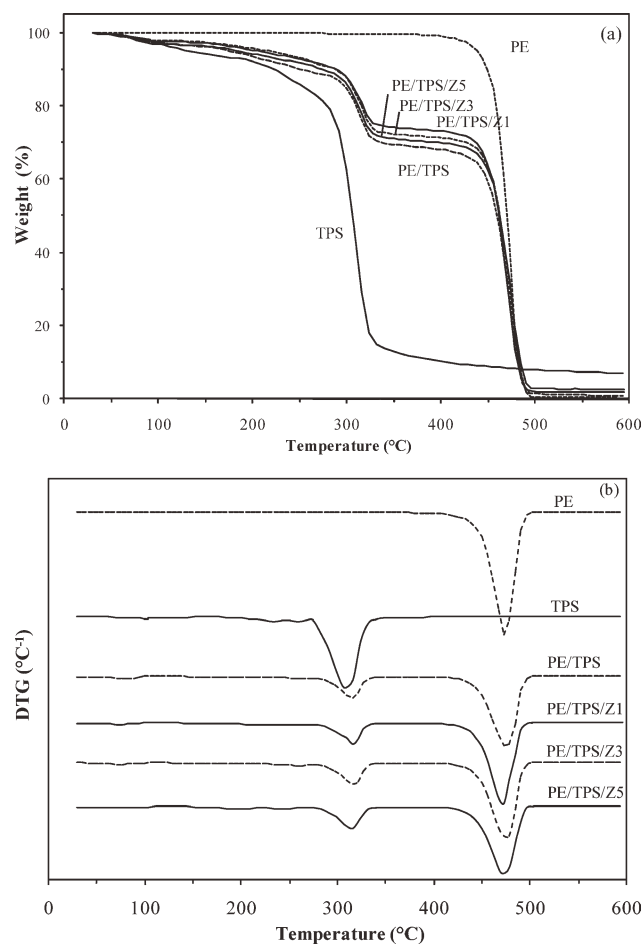
stretching).<sup>29,33</sup> For PE, characteristic peaks appeared at wavenumbers of  $\sim 730\text{--}720\text{ cm}^{-1}$  (C–H rocking),  $1464\text{ cm}^{-1}$  (C–H bending), and  $\sim 2940\text{--}2850\text{ cm}^{-1}$  (C–H stretching).<sup>34</sup> After melt blending PE with TPS, the obtained blend showed the main characteristic peaks of both PE and TPS without significant changes in peak shape and position, indicating no strong intermolecular interactions occurring between these polymers. After incorporating 1–5 wt % of zeolite 5A into the PE/TPS blend, the obtained PE/TPS/Z composites showed only main characteristic peaks of the blend, without the characteristic peaks of zeolite 5A. This could be due to a low concentration of zeolite 5A being used and its characteristic peaks being dominated by those of TPS. In addition, no significant shift of PE and TPS peaks was observed in the composites, suggesting that zeolite 5A was physically dispersed in the PE/TPS blend matrix.

### Thermal properties of PE/TPS/Z composites

Thermogravimetric (TG) and derivative thermogravimetric (DTG) thermograms of PE, TPS, PE/TPS blend, and PE/TPS/Z composites examined by TGA technique are illustrated in Figure 4. PE showed a single weight loss step with  $T_d$  of  $471.6^\circ\text{C}$ , as determined from the DTG curve. For TPS, three decomposition steps were observed at temperatures of  $\sim 100, 210\text{--}250,$  and  $280\text{--}330^\circ\text{C}$ , corresponding to the loss of moisture content, evaporation of glycerol, and thermal degradation of TPS, respectively.<sup>9</sup> After melt blending TPS with PE (30 : 70 wt/wt), the  $T_d$  of TPS increased from  $314.5$  to  $327.9^\circ\text{C}$  without significantly affecting that of PE. However, after incorporating 1–5 wt % of zeolite 5A, the  $T_d$ s of TPS and PE in the blend decreased by  $\sim 12\text{--}15$  and  $\sim 5\text{--}8^\circ\text{C}$ , respectively. This indicates that the presence of zeolite 5A somewhat accelerates thermal degradation of the PE/TPS blend. However, increasing the concentration



**Figure 3** FTIR spectra of zeolite 5A, PE, TPS, PE/TPS blend, and PE/TPS/Z composites.

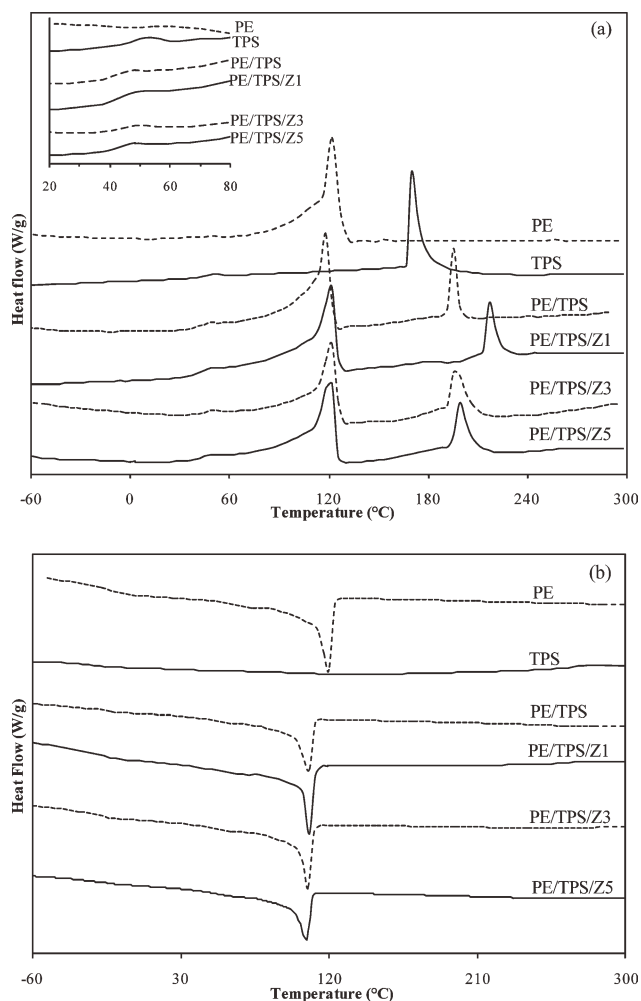


**Figure 4** TGA thermograms of PE, TPS, PE/TPS blend, and PE/TPS/Z composites: (a) TG and (b) DTG curves.

of zeolite 5A from 1 to 5 wt % had no significant effect on  $T_g$ s of both TPS and PE.

Thermal transitions of PE, TPS, PE/TPS blend, and PE/TPS/Z composites determined from their heating and cooling cycles by DSC thermograms are shown in Figure 5 and Table II. Glass transition temperature ( $T_g$ ) and melting temperature ( $T_m$ ) of the samples were determined upon heating the samples from  $-60$  to  $300^\circ\text{C}$ . The  $T_g$  of TPS occurred at a temperature of  $51.6^\circ\text{C}$  (Table II). However the  $T_g$  of PE was unable to be observed due to the DSC instrument cooling limit of  $-80^\circ\text{C}$ . For the PE/TPS blend, the  $T_g$  of TPS decreased to  $47.4^\circ\text{C}$ . With the addition of 1–5 wt % of zeolite, the  $T_g$  of TPS in the PE/TPS blend decreased significantly ( $P \leq 0.05$ ), by  $\sim 3\text{--}4^\circ\text{C}$ , possibly because the presence of zeolite 5A could increase the chain mobility of PE and TPS, as well as the miscibility between the two polymers.<sup>35</sup> Endothermic transitions at temperatures of  $121.2$  and  $169.2^\circ\text{C}$  corresponded to  $T_m$ s of neat PE and TPS, respectively. After melt blending these two polymers, the blend showed melting temperatures at both  $116.3$  and  $196.4^\circ\text{C}$ , corresponding to those of PE and TPS ( $T_{m1}$  and  $T_{m2}$ ), respectively. Incorporation

of zeolite 5A (1–5 wt %) into the PE/TPS blend resulted in significantly increased  $T_m$ s of PE and TPS ( $P \leq 0.05$ ), to  $\sim 120$  and  $\sim 195\text{--}239^\circ\text{C}$ , respectively. Unlike PE, the  $T_m$  of TPS depend on the concentration of zeolite 5A, as the melting temperature significantly decreased ( $P \leq 0.05$ ), from  $238.6$  to  $196.2^\circ\text{C}$  when the zeolite 5A content increased from 1 to 3 wt %; however, further increases in zeolite 5A concentration had no significant effect ( $P > 0.05$ ) on the  $T_m$  of TPS in the PE/TPS/Z composites. Upon cooling PE, TPS, PE/TPS blend, and PE/TPS/Z composites down to a temperature of  $-60^\circ\text{C}$ , only crystallization temperature ( $T_c$ ) of PE was observed. After melt blending PE with TPS, the  $T_c$  of PE decreased from  $122.1$  to  $108.1^\circ\text{C}$ , indicating that the presence of TPS hindered the molecular motion of PE during cooling, in accordance with a report by Liu et al.<sup>36</sup> Addition of 1–3 wt % of zeolite 5A had no significant effect ( $P > 0.05$ ) on the  $T_c$  of PE in the PE/TPS blend; however, further increases in zeolite 5A content to 5 wt % led to a significant decrease ( $P \leq 0.05$ ) of the



**Figure 5** DSC thermograms of PE, TPS, PE/TPS blend, and PE/TPS/Z composites: (a) heating and (b) cooling cycles.

**TABLE II**  
Thermal Properties of PE, TPS, PE/TPS Blend, and PE/TPS/Z Composites

Samples	$T_g$ (°C)	$T_m$ s (°C)		$T_c$ (°C)
		$T_{m1}$	$T_{m2}$	
PE	–	$121.2 \pm 2.1^a$	–	$122.1 \pm 0.2^a$
TPS	$51.6 \pm 1.4^a$	–	$169.2 \pm 2.4^c$	–
PE/TPS	$47.4 \pm 1.9^b$	$116.3 \pm 2.1^b$	$196.4 \pm 1.7^b$	$108.1 \pm 0.2^b$
PE/TPS/Z1	$43.0 \pm 0.9^c$	$122.3 \pm 1.1^a$	$238.6 \pm 1.9^a$	$108.3 \pm 0.3^b$
PE/TPS/Z3	$44.2 \pm 1.0^c$	$122.0 \pm 1.9^a$	$196.2 \pm 0.7^b$	$107.6 \pm 0.5^b$
PE/TPS/Z5	$43.4 \pm 1.2^c$	$122.2 \pm 1.3^a$	$195.2 \pm 2.3^b$	$105.1 \pm 1.1^c$

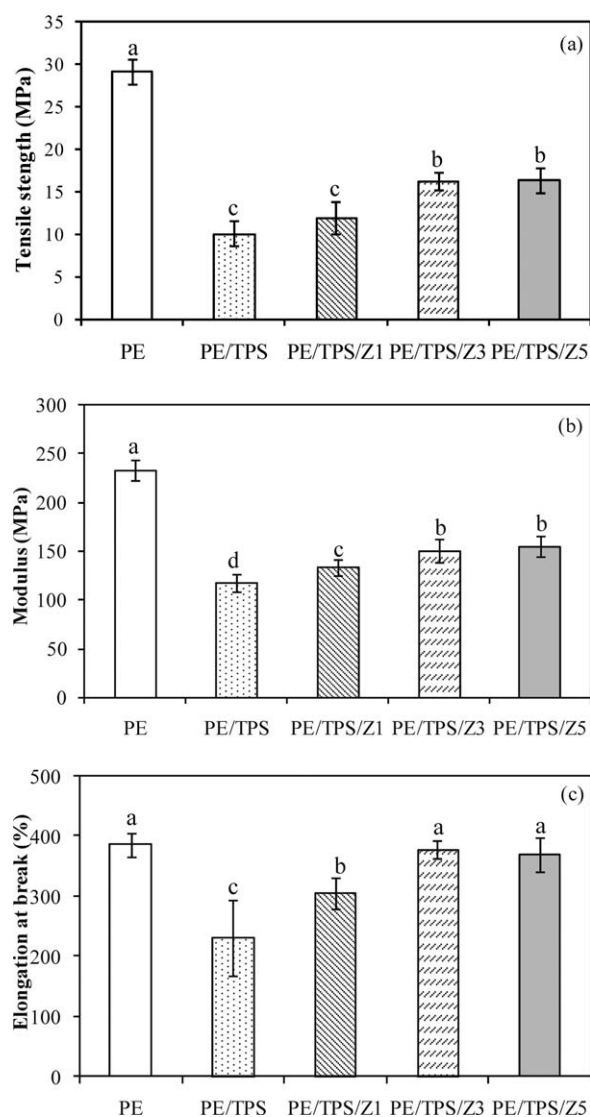
Different superscript letters indicate significant differences ( $P \leq 0.05$ ).

$T_c$  to 105.1°C. This result is particularly interesting because zeolite is usually considered as a nucleating agent and the addition of zeolite generally increases the  $T_c$  of polymer matrix. In this work, the negative effect of zeolite 5A on the crystallization of PE could be described by that the presence of zeolite 5A improves the miscibility between PE and TPS and the starch molecules depress the crystallization of PE during cooling. The decrease in  $T_c$  of a polymer due to improved miscibility of a polymer blend composite was also reported by Lai et al.<sup>37</sup> In their work, adding 4.8 wt % of organoclay to PP/PP-g-MA and PP/POE-g-MA blends enhanced the miscibility of the blend composites and, therefore, decreased the  $T_c$  of PP by  $\sim 4$ –6°C.

### Mechanical properties of PE/TPS/Z composites

Figure 6 presents a comparison of tensile properties of PE, PE/TPS blend, and PE/TPS/Z composites. Tensile strength, modulus, and elongation at break of PE were 29.2 MPa, 232.8 MPa, and 386.3%, respectively. Melt blending of PE with 30 wt % of TPS resulted in significantly decreased ( $P \leq 0.05$ ) tensile strength, modulus, and elongation at break of PE, to 10.1 MPa, 117.1 MPa, and 231.6%, respectively. This could be caused by the immiscibility between PE and TPS, according to SEM results as shown in Figure 1. However, inclusion of 1 wt % of zeolite 5A significantly increased ( $P \leq 0.05$ ) elongation at break of the PE/TPS blend to 305.8% and modulus to 133.0 MPa. In addition, a further increase in zeolite 5A content to 3–5 wt % resulted in significantly increased ( $P \leq 0.05$ ) tensile strength of  $\sim 16.3$  MPa. The modulus of PE/TPS/Z composites significantly increased ( $P \leq 0.05$ ) from 133.0 to 149.9 and 154.5 MPa when zeolite 5A content increased from 1 to 3 and 5 wt %, respectively. Increasing zeolite 5A concentration from 1 to 3 wt % resulted in significantly increased ( $P \leq 0.05$ ) elongation at break of PE/TPS/Z composites, from 305.8 to 388.2%; however, further increasing the zeolite 5A content to 5 wt % had no significant effect on the elongation at break. In general, incorporation of zeolite 5A increased the tensile

strength, modulus, and elongation at break of the PE/TPS blend by up to  $\sim 60$ , 30, and 70%, respectively. The improved tensile properties could be resulted from the increases in: (i) miscibility between



**Figure 6** Tensile properties of PE, TPS, PE/TPS blend, and PE/TPS/Z composites: (a) tensile strength, (b) modulus, and (c) elongation at break. Different letters indicate significant differences ( $P \leq 0.05$ ).

PE and TPS (Fig. 1) and (ii) adhesion between zeolite 5A and the polymer blend matrix.<sup>19,20,38</sup>

## CONCLUSIONS

Incorporation of zeolite 5A (1–5 wt %) improved the miscibility and mechanical properties of PE/TPS blend. In addition, incorporating zeolite 5A slightly decreased: (i) thermal stability of PE (~ 5–8°C) and TPS (~ 12–15°C); (ii) glass transition temperature of TPS (~ 3–4°C); and (iii) crystallization temperature of PE (up to ~ 3°C). Compounding the PE/TPS blend with zeolite 5A significantly increased tensile strength, modulus, and elongation at break by up to ~ 60, 30, and 70%, respectively. Tensile strength, modulus, and elongation at break of PE/TPS/Z composites increased from ~ 12 to 16 MPa, 133 to 154 MPa, and 305 to 390%, respectively, when increasing the zeolite 5A content from 1 to 5 wt %. Finally, zeolite 5A is considered as both a promising physical compatibilizer and reinforcing filler to improve the miscibility and the properties of hydrophilic and hydrophobic polymer blends.

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