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In-situ poly(butylene adipate-*co*-terephthalate)/soy protein concentrate composites: Effects of compatibilization and composition on properties

Feng Chen, Jinwen Zhang*

Materials Science Program & Composite Materials and Engineering Center, Washington State University, Pullman, WA 99164-1806, United States

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ABSTRACT

In this study, soy protein concentrate (SPC) was blended as plastic with poly(butylene adipate-*co*-terephthalate) (PBAT). An extra amount of water was added to SPC prior to compounding to ensure that SPC behaved like a plastic during mixing. Because of the extensive crosslinking and agglomeration during compounding and the fact that most water was evaporated after drying the compounds, the SPC phase was not able to flow like a plastic in the subsequent processing. Therefore, the compounds became in-situ formed composites. The effects of SPC content and compatibilizer on the morphological, rheological, tensile and dynamic mechanical properties of PBAT/SPC blends were studied. Using maleic anhydride grafted PBAT as compatibilizer resulted in fine domain sizes and good dispersion of SPC and hence improved tensile and dynamic mechanical properties. In the presence of compatiblizer, the formation of percolated SPC network structure was observed at high SPC concentrations, subsequently, resulted in drastic changes in rheological properties, mechanical and dynamic mechanical properties of the blends.

1. Introduction

In recent years soy protein (SP) has received great interest for plastic applications. SP can be used as a plastic material alone or as a component in polymer blends. When SP is used alone or blended with other natural polymers, the resulting SP plastics were very water/moisture sensitive and exhibited poor flowability in processing such as extrusion or injection molding unless a large amount of plasticizer was added [1,2]. Blending SP with other hydrophobic thermoplastic polymers is the most economic approach to overcome many problems associated with SP plastic materials. SP has been blended with various biodegradable polymers such as poly(butylene succinate-*co*-adipate) [3], polycaprolactone [3–9], poly(hydroxyl ester ether) [6], poly-ε-caprolactone [10], poly(vinyl alcohol) [11] and poly(butylene adipate-*co*-terephthalate) [12], and with non-biodegradable polymers such as poly(ethylene-*co*-ethyl acrylate-*co*-maleic anhydride) [13], polyurethane [14] and styrene–butadiene latex [15]. However, in these studies SP was only used as an organic particulate filler. Although such blends generally exhibited improved processibility, water resistance and/or toughness than the neat SP plastics, they often yielded lower strength than the neat polymers, especially at high SP loading levels.

We recently investigated the blending of soy protein concentrate (SPC) containing extra water with PLA [16,17] and poly (butylene adipate-*co*-terephthalate) (PBAT) [18]. The extra water combined with the absorbed water in the as received SPC together was able to gelate SPC to a certain degree and subsequently plasticize the gelled SPC, rendering certain flowability/deformability of the SPC phase in the blending process. The deformability of the SPC phase in processing, as seen in the shape of stretched threads, and the SPC phase structure clearly depended on water content in the pre-compounding SPC [18]. As a result, the SPC domains in the resulting blends displayed an interconnected thread network structure [18], and even a co-continuous structure in certain cases [16]. These SPC blends prepared from SPC containing extra water demonstrated significantly higher strength and modulus than the blends using SPC as filler [17,18]. It is worth mentioning that due to extensive agglomeration and crosslinking of SP occurred during compounding and further drying after extrusion, the SP phase in the blends became very rigid and lost its flowability in subsequent processing, therefore the blends behaved like in-situ formed composites. This is particularly valid in the blends with soft polymers such as PBAT whose modulus is only about one-twelfth of that of SPC [18]. Similar delicate phase structures and hence superior properties of SP blends obtained by having extra water in the pre-compounding SP were also noted in a few other recent studies [19–22].

Compatibilizer is widely used to improve the compatibility between SP filler and polyester phases. For example, methylene

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* Corresponding author. Tel.: +1 509 335 8723; fax: +1 509 335 5077.
E-mail address: jwzhang@wsu.edu (J. Zhang).

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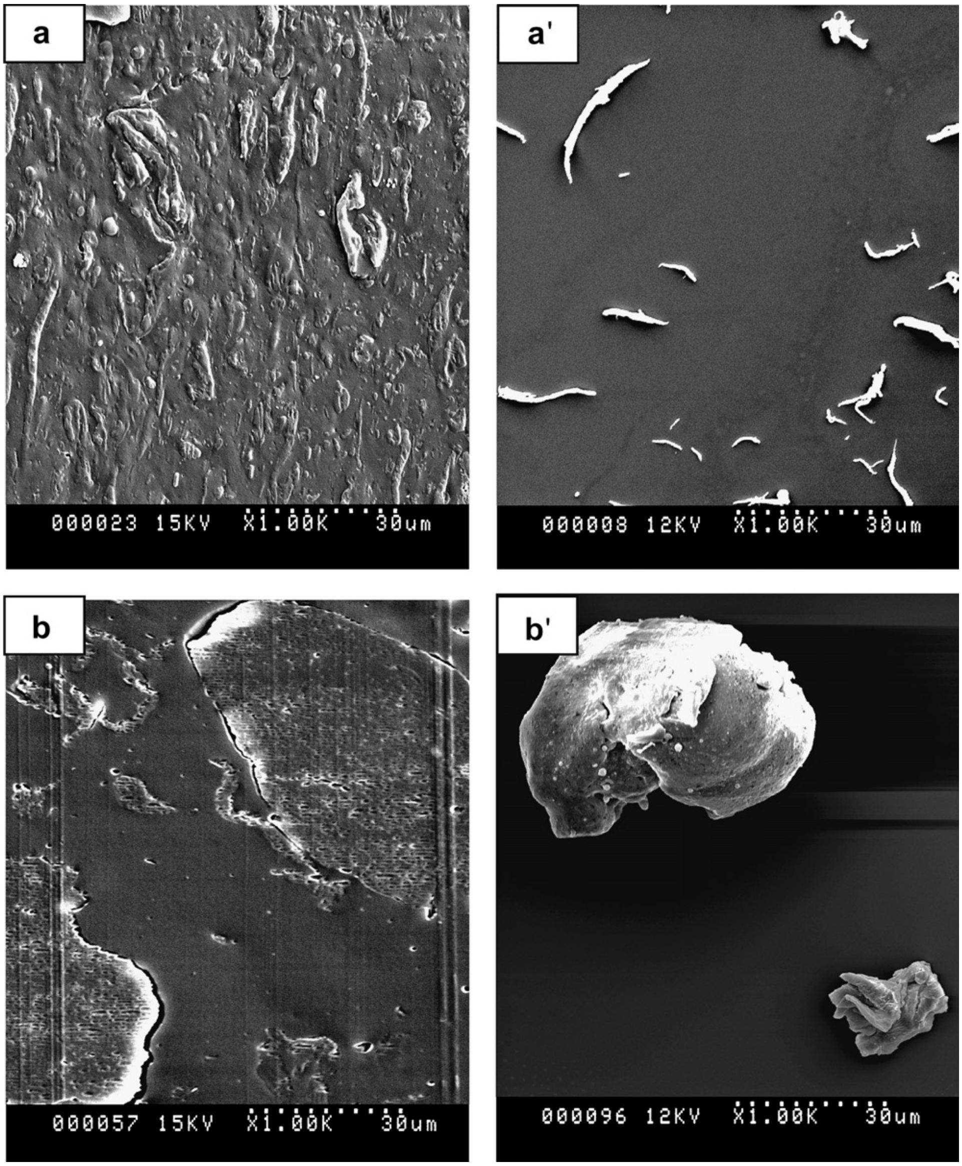

Fig. 1. SEM micrographs showing the effect of PBAT-*g*-MA on the phase morphology of PBAT/SPC (70/30 w/w) blends. a & a′: containing 3 wt% PBAT-*g*-MA on the basis of the total PBAT/SPC weight; b & b′: without PBAT-*g*-MA. Left column: morphological structures of the blends in the longitudinal direction; right column: extracted SPC after removing PBAT by chloroform.

diphenyl diisocyanate [4], toluene diisocyanate [9], maleic anhydride (MA) grafted polyesters [3] and glutaraldehyde [23] have been used to improve the interfacial adhesion and dispersion of SP in the matrix polymers. When SP was processed as plastic in blending with PLA, poly(2-ethyl-2-oxazoline) was found to be an effective compatibilizer, resulting in fine phase structure of SP and improved properties of the blends [16,17]. On the other hand, SP content in the blends also plays an important role in determining the performance of the polymer blends [11,16].

In this study, a series of PBAT/SPC blends was prepared by extrusion and the test specimens were prepared by injection molding. The major objective of this study was to investigate the effects of SPC loading level and compatibilizer on the phase structure and the mechanical properties of PBAT/SPC blends. Water content in the pre-compounding SPC was fixed at 22.5%. Effects of SPC content and comaptibilizer (maleated PBAT) on morphology and performance of PBAT/SPC blends were studied in detail. The critical SPC content for the formation of percolated SPC phase structure was identified.

2. Experimental

2.1. Materials

SPC (Arcon F) was provided by ADM (Decatur, IL) and contained ca. 7.5 wt% moisture as received. PBAT (Ecoflex F BX 407) was provided by BASF (Florham Park, NJ). Maleic anhydride (MA) (95%) was purchased from Aldrich. Maleic anhydride (MA) grafted PBAT (PBAT-*g*-MA) was prepared by reactive mixing of PBAT with 5% MA and 0.5% dicumyl peroxide on the basis of PBAT weight, and the unreacted MA was removed under high vacuum at 80 °C [24]. The degree of grafting was found to be 1.40 wt% by titration.

2.2. Blend preparation

SP was formulated and contained the following ingredients by weight: SPC (100 parts, on the basis of dry weight), sodium sulfite (0.5 parts), glycerol (10 parts) and water (15 parts). The formulated SPC was mixed using a kitchen blender, then stored in sealed plastic

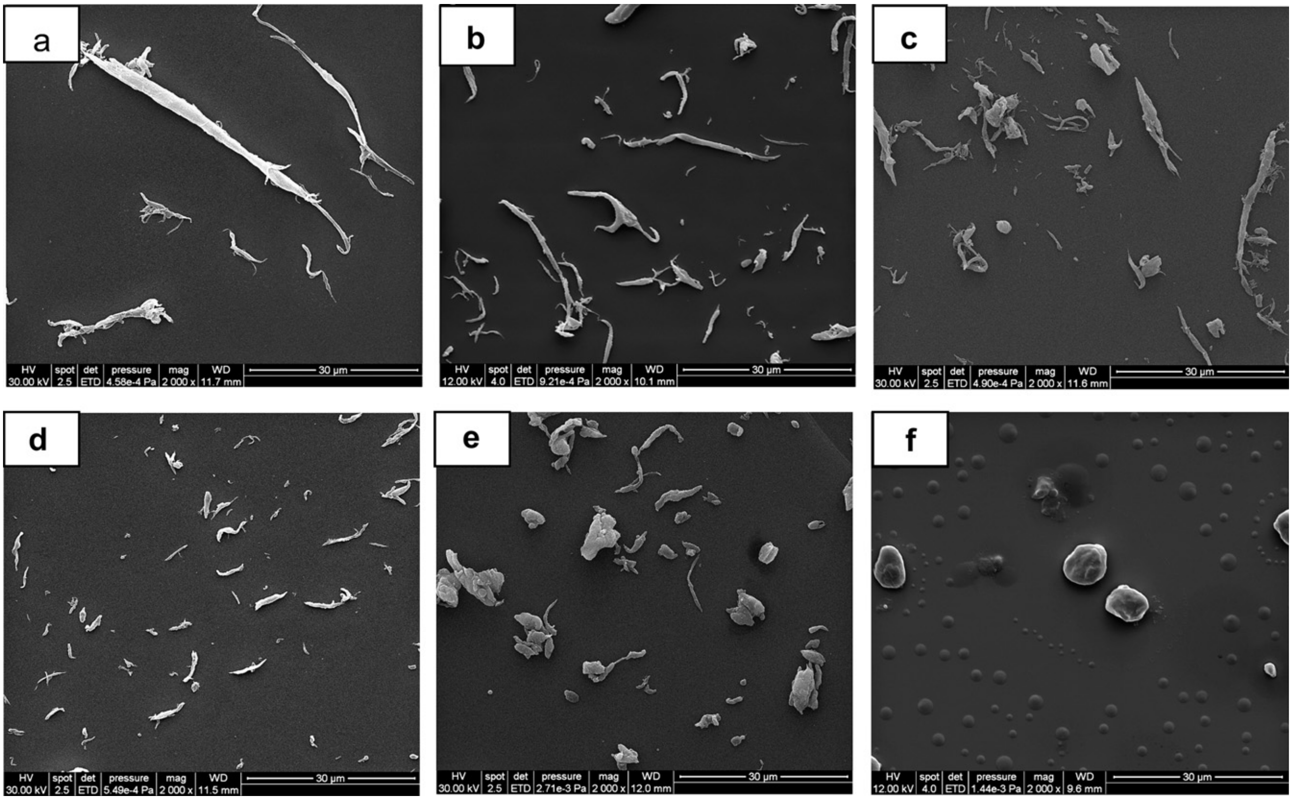

Fig. 2. Effect of SPC content on the SPC phase morphology in the compatibilized PBAT/SPC blends. SPC was isolated by Soxhlet extraction of PBAT using chloroform. SPC content in the blends: a, 50%; b, 30%; c, 25%; d, 20%; e, 15%; f, SPC particle as received. SEM samples were prepared by spin coating the isolated SPC on mica slices.

bags and left overnight at room temperature to equilibrate. The mixture of formulated SPC, PBAT and/or PBAT-*g*-MA was compounded using a co-rotating twin-screw extruder (Leistriz ZSE-18) equipped with 18-mm diameter screws having an L/D ratio of 40. The screw speed was maintained at 80 rpm for all runs, and the eight controlled temperature zones were set at 99, 110, 145, 145, 145, 145, 145 and 140 °C, respectively, ranging from the feeding segment to the die adaptor. The extrudate was cooled in a water bath and subsequently granulated by a strand pelletizer. Pellets were exposed in the air for 4 h to further evaporate the residual surface moisture and then dried in a convection oven at 90 °C for 12 h or longer until the residual water within the pellets was less than 1%. A Sumitomo injection molding machine (SE 50D) was used to prepare the test specimens. The temperature zones of the barrel were set at 155, 160, 160 and 155 °C from the feeding section to the nozzle. Mold temperature was set at 50 °C and cooling time was ca. 30 s. All specimens for mechanical test and other characterizations were conditioned for one week at 23 ± 2 °C and 50 ± 5% RH.

2.3. *Tensile test*

Tensile tests were performed on an 8.9-kN, screw-driven universal testing machine (Instron 4466) equipped with a 10-kN electronic load cell and machine grips. Testing was conducted at

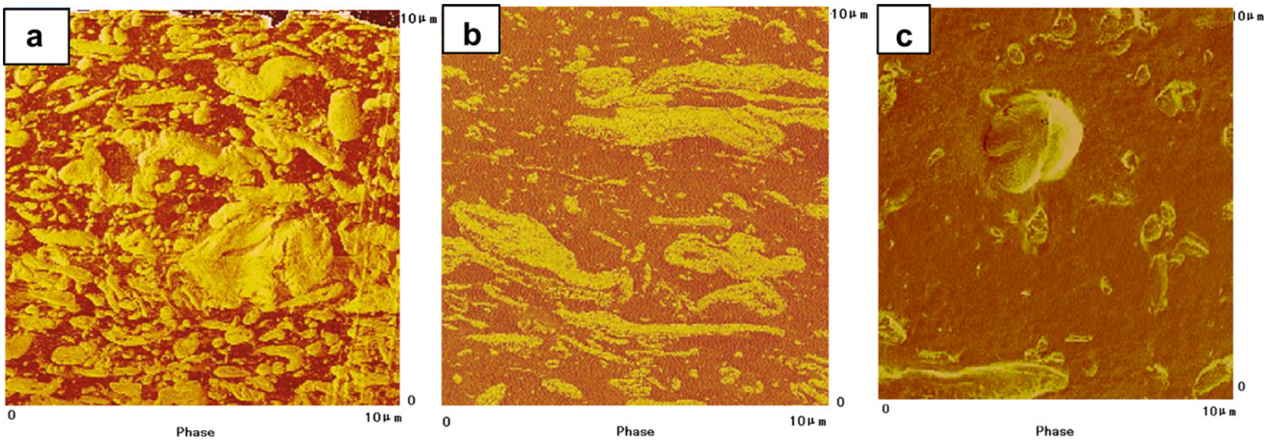

Fig. 3. High resolution AFM micrographs of the PBAT/SPC blends containing 3 wt% PBAT-*g*-MA on the basis of the total PBAT/SPC weight. a: PBAT/SPC 50/50 (w/w); b: PBAT/SPC 70/30 (w/w); c: PBAT/SPC 85/15 (w/w).

a crosshead speed of 5 mm/min with strains measured using a 25-mm extensometer (MTS 634.12.E-24). All tests were carried out according to the ASTM standard (ASTM D638, type I specimens) and 5 replicates were tested for each sample to obtain an average value.

2.4. Dynamic mechanical analysis and rheology test

Dynamic mechanical properties were measured by a dynamic mechanical analyzer (DMA, TA Q-800). DMA specimens ($12.6 \times 3.2 \times 35$ mm^3) were cut from the injection molded samples and conditioned in the same environment as tensile samples. DMA test was conducted on a single-cantilever fixture at a frequency of 1 Hz. All tests were conducted at an amplitude of 30 μm using a 2 °C/min temperature ramp from −70 °C to 130 °C. The weight loss of specimen after DMA test was measured and found to be ca. 1% for all samples, which could be approximately assumed as the residual moisture and some volatiles in the SPC phase.

Dynamic rheological properties of the PBAT/SPC blends were measured using a strain-controlled rheometer (Rheometric Scientific, RDA III), with a parallel-plate geometry ($d = 25$ mm). The gap distance between the parallel plates was 1 mm for all tests. A strain sweep test was initially conducted to determine the linear viscoelastic region of the materials. Dynamic frequency sweep test (strain: 3%, frequency: 0.01–500 rad/s) was performed at 160 °C. All test samples were cut from the injection molded specimens after conditioning. Since water content of the specimen was assumed to be ca. 1% as determined by DMA test, no additional protection during the test was taken.

2.5. Microscopy

Scanning Electron Microscopy (SEM, Hitachi S-570) and Field Emission Scanning Electron Microscopy (FE SEM, Quanta 200F) were used to examine the SPC domain structure and morphology of the blends. All specimens were sputter coated with gold prior to examination. AFM measurements were carried out using a NanoScope IIIa controller equipped with an AS-130(“J”) scanner in ambient conditions. Silicon cantilevers NSC15/no Al (MikroMasch, USA) were used for the intermittent contact (tapping) mode operation. Scan rate was varied from 0.1 to 0.5 Hz, depending on the image quality. The AFM sample was taken from the central part of the injection molded samples and the AFM smooth section for observation was the lateral surface (i.e. the flow direction) prepared by a Powertome X (Boeckeler Instrument) ultramicrotome. The SPC phase was separated by complete removal of PBAT using chloroform by Soxhlet extraction for 7days. The isolated SPC was added into chloroform (99+%) and was gently stirred for 30 s to maximally retain the original SPC phase structure, and then the suspension was spin coated on mica slices.

3. Results and discussion

3.1. Effects of compatibilizer and SPC loading level on SPC phase morphology

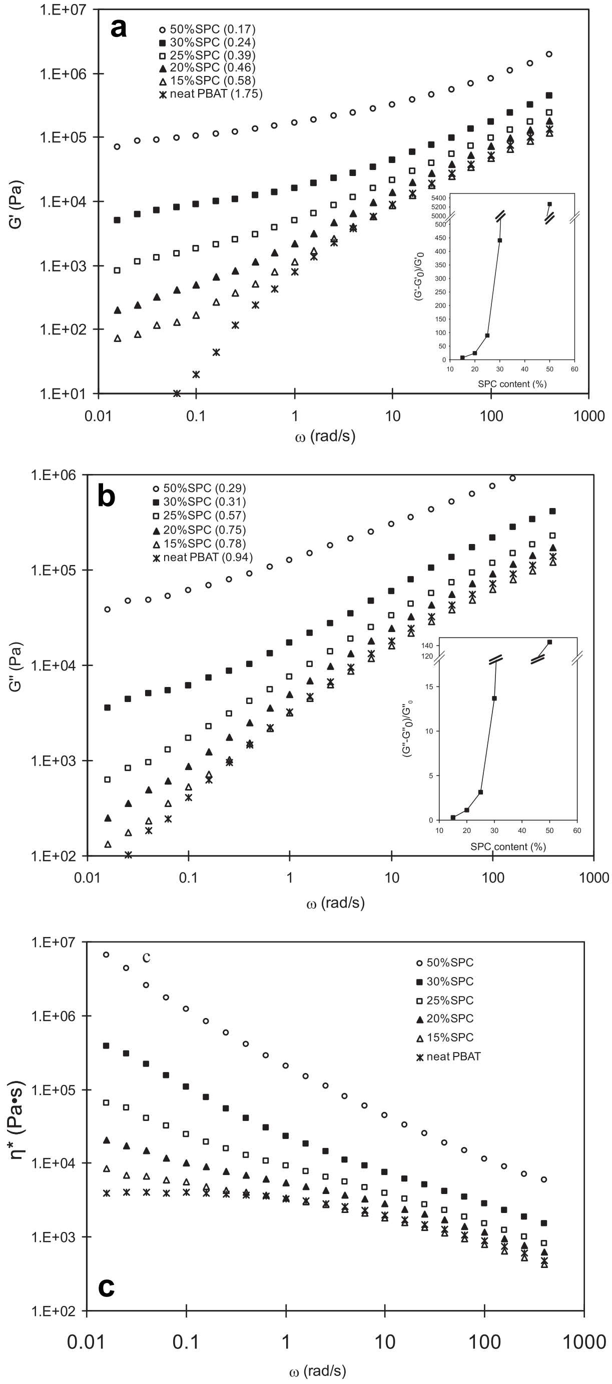

Fig. 4. Effect of SPC content on dynamic rheological properties of the compatibilized PBAT/SPC blends. Strain = 3%, temperature = 160 °C. The insets showed the relative increase in modulus at $\omega = 0.1$ rad/s with respect to those of neat PBAT (G'_0 and G''_0) as a function of SPC content in blends. The number in parenthesis was the scaling exponent n value in the terminal region.

Fig. 1 shows the effects of PBAT-*g*-MA as compatibilizer on SPC domain size and phase structure of the blends. By adding PBAT-*g*-MA, the phase structure of the resulting blend changed from coarse to fine and the shape of the SPC domains changed from large particles to fine threads. MA grafted polymers are often used to increase the interfacial adhesion between hydrophobic synthetic polymers and various hydrophilic natural polymers [3]. The anhydride groups were likely to react with the amino groups and the hydroxyl groups of carbohydrates in SPC, therefore greatly decreased the interfacial tension which played a key role in reducing the sizes of the dispersed phase [25]. Development of phase morphology of a polymer blend is governed by the balance of breakup and coalescence of the dispersed phase. Without compatibilizer, the coalescence of SPC suppressed the breakup due to the high surface tension, resulting in large SPC domain sizes.

Fig. 2 shows that the size and shape of the SPC domains also varied with SPC content. SPC appeared to experience different degrees of deformation depending on SPC loading level. As SPC

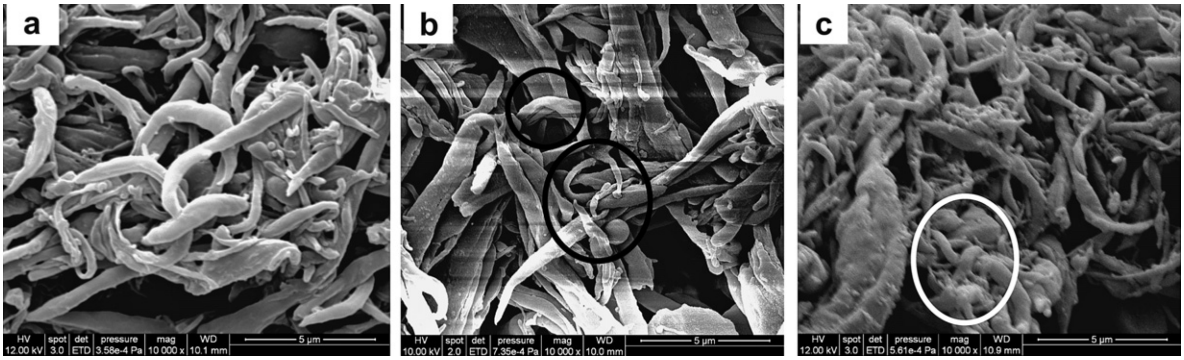

Fig. 5. FE SEM micrographs of the Soxhlet extracted SPC phase in the compatibilized PBAT/SPC blends showing the mechanical interlocks in the percolated SPC phases. a: PBAT/SPC 50/50 (w/w); b: PBAT/SPC 70/30 (w/w); c: PBAT/SPC 75/25 (w/w).

content increased, the SPC domains became finer and more stretched. At 15% SPC, a large portion of SPC existed in approximately spherical and ellipsoidal particulates. When SPC content increased to 30 or 50% in the blends, however, most of SPC domains became fine and elongated threads. Because all blends in Fig. 2 were prepared with SPC containing 15% extra water prior to compounding, a similar deformability of the SPC domain was expected during compounding. On the other hand, the viscosity of the blend during mixing increased with SPC content, resulting in increasing shear stress experienced by the SPC phase. Therefore, SPC underwent larger deformation and appeared more stretched with increasing SPC content.

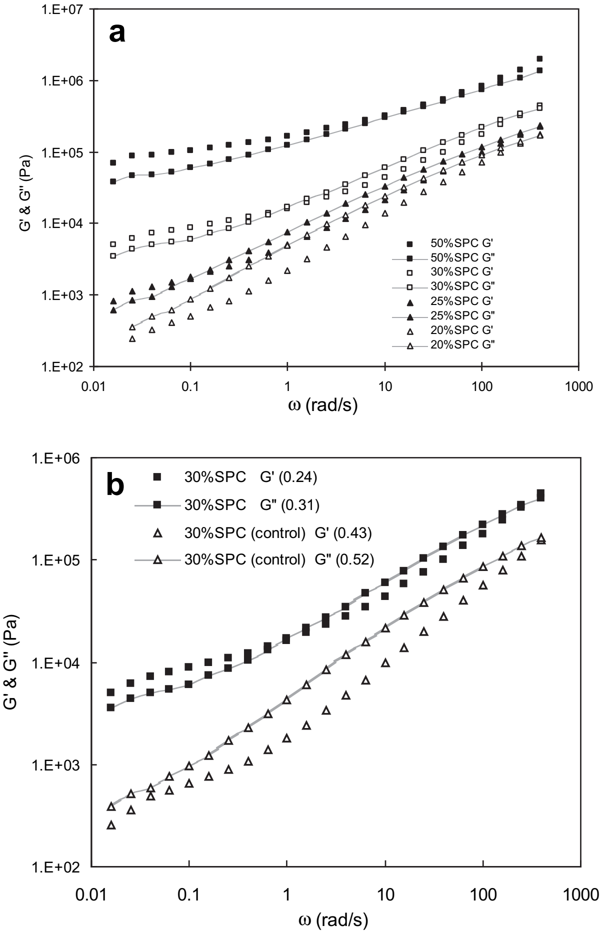

Fig. 6. Crossover of G′ and G″ curves indicating that the percolation threshold of the compatibilized blends (a) is at 25% SPC and the effect of compatibilizer (b).

The changes of SPC size and shape with SPC content in turn influenced the morphology of the blends. Fig. 3 shows the high resolution phase topography of the blends. Tapping mode AFM was performed on the blends. Because the elastic modulus of SPC is higher than that of PBAT, the bright yellow area is the SPC phase and the dark brown area is the PBAT phase. Fig. 3a and b reveals the percolated SPC phase structure in the blends having 50 and 30% SPC, respectively, and Fig. 3c shows the dispersed SPC phase in the matrix for the blend with 15% SPC.

3.2. Dynamic rheological properties and rheological percolation

We previously demonstrated that blending PBAT with SPC containing extra water ended up with the formation of in-situ PBAT/SPC composites [18]. The modulus of the SPC phase in the blends was estimated to be more than twelve times higher than that of the PBAT phase. This was attributed to the occurrences of severe agglomeration and crosslinking of soy protein during compounding and the evaporation of most water after extrusion and drying of the blends, therefore SPC mostly lost its melt-like flowability and behaved more solid-like afterward. Accordingly, the resulting PBAT/SPC blends displayed rheological behavior similar to that of composites. Dynamic rheological measurement is a sensitive method in characterizing the morphological structure of polymer blends and composites because the structure of polymer

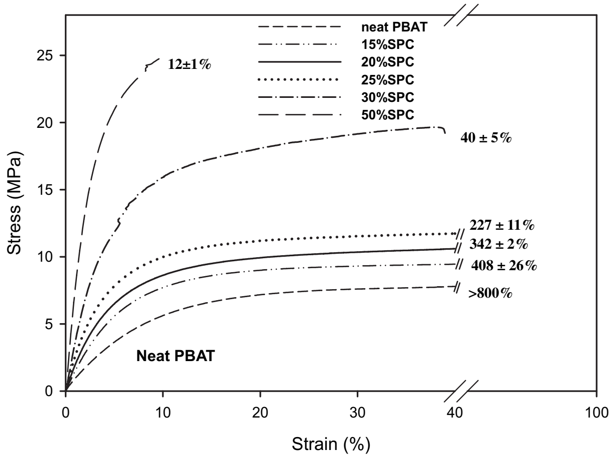

Fig. 7. Stress-strain curves of the compatibilized PBAT/SPC blends with different SPC contents.

materials is reserved under small strain test condition [26]. Fig. 4 shows that both storage modulus (G′) and loss modulus (G″) of the blends increased monotonously with SPC content. PBAT melt displayed a typical liquid-like behavior in the terminal (low frequency) zone where both G′ and G″ smoothed out. It is well known that the addition of rigid filler into a neat polymer will result in pronounced elastic properties and long relaxation times [27]. The viscoelastic response of the blends was mainly altered in the terminal zone. As SPC content increased from 0 to 50%, in the terminal zone, the slopes (n, scaling exponent) of log(G′) vs. log(ω) and log(G″) vs. log(ω) changed from 1.75 to 0.17 and from 0.94 to 0.29, respectively. This increasing frequency-independence of both G′ and G″ with SPC content suggests that the melt became pseudo-solid-like at low frequencies. This obvious deviation of rheological properties of the blends from the typical liquid-like behavior of pure polymer melt was attributed to the solid-like nature of SPC in the melt. The effects of SPC content on G′ and G″ of the blend melts can also be seen in the relative increases of G′ and G″ with respect to those of the neat PBAT, as shown in the insets of Fig. 4a and b. The drastic decrease in scaling exponent and the quick rise in relative increases of G′ and G″ at high SPC content (25% and higher) indicate the formation of certain degree of interconnected SPC network structure (percolation) in the matrix [18,28].

Furthermore, the increased melt elasticity of the blends was also reflected in the influence of SPC on complex viscosity η*. Compared with the η* of the pure polymer, a general increase in η* of the blends was noted in the whole frequency range and the magnitude of increase was especially large in the terminal zone (Fig. 4c). In the terminal zone, the plot of log(η*) vs. log(ω) for the neat PBAT showed a Newtonian (primary) plateau. For the blends, this primary plateau quickly disappeared with increasing SPC content and the melt displayed a significant shear-thinning behavior at higher SPC content across the whole frequency range, also suggesting the formation of percolated SPC structure.

The phase morphology of composites depends on filler size, geometry and content [29,30]. As seen in Fig. 2, SPC was overwhelmingly in elongated threads in the blends when its content was 25% or higher, hence possessing larger average aspect ratios than the SPC which took 20 wt% or lower in the blends. Fig. 5 shows the percolation structures of the SPC threads observed after the PBAT phase was extracted using chloroform. Such network structure was not found in the blends with 15 and 20% SPC and the blends without PBAT-*g*-MA. It is interesting to note the existence of some interlocking loops of the SPC threads in the percolated structure. Such interlocks might also contribute to the high elasticity of the melt in terminal zone and the reinforcement of the blends as discussed in the latter section.

The formation of pseudo-solid-like network structure of the percolated threads was also manifested in the plots of log(G′) and log(G″) values vs. log(ω) (Fig. 6). Similar to the neat PBAT, both blends with 15 and 20% SPC in which SPC was homogeneously dispersed in PBAT showed lower G′ than G″ within the whole frequency range tested, suggesting SPC behaved like an ordinary particulate filler in these two cases (Fig. 6a). However, all blends with 25–50% SPC in which the SPC network structure was formed displayed higher G′ and G″ in the low frequency region and the disparity was proportional to the SPC content. At higher frequencies, crossover of G′ and G″ was noted. This was probably due to the destruction of the network structure at high shear rates and the melt again behaved more like a dispersed polymer composite system. This argument was supported by the FE SEM micrographs (not shown) of the SPC phase isolated after dynamic rheology test. The SEM analysis indicated the major clusters of percolated SPC threads shown in Fig. 5 were disrupted after dynamic rheology test; instead, much smaller domains of SPC threads were noted. Similar behavior was also reported for the polystyrene/carbon nanotube composites with percolated structures [28]. The overtaking G″ by G′ in the melt state was also observed in the curing of thermosetting resins such as polyurethane above the gel point where the crosslinked network structure started to built up [31]. It is worth mentioning that the crossover point shifted to higher frequency as the SPC content increased, being 0.1, 1 and 10 rad/s for the blends containing 25, 30 and 50% SPC, respectively. This shift was attributed to higher degree of interconnectivity and interlocking of the percolated structure. Similar shift phenomenon was also mentioned in the study of linear viscoelastic response of semi-flexible polymer [32]. It should also be pointed out that all blends without PBAT-*g*-MA exhibited higher G″ than G′ in the whole frequency range, as shown in Fig. 6b.

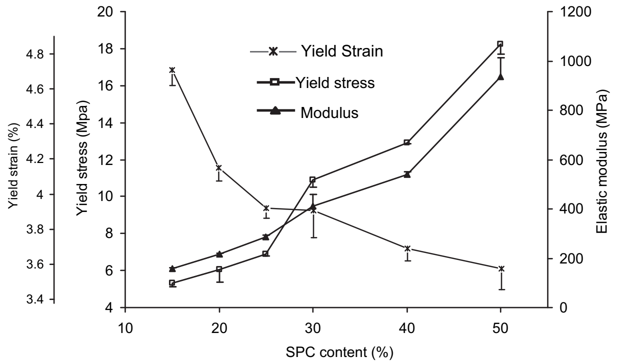

Fig. 8. Effect of SPC content on yield stress/strain and elastic modulus of the compatibilized PBAT/SPC blends.

Table 1
Effects of composition and compatibilizer on tensile properties and T_g of PBAT/SPC blends.

PBAT/SPC (w/w)	PBAT-*g*-MA (parts)	E (MPa)	σ_b (MPa)	ε_b (%)	σ_y[a]	ε_y	T_g[b] (°C)
50/50	3	937 ± 77	24.5 ± 0.7	11.6 ± 1.6	18.3 ± 0.6	3.6 ± 0.1	−16.2
	0	612 ± 28	5.6 ± 0.1	8.9 ± 2.9	5.3 ± 0.2	1.9 ± 0.0	−14.5
70/30	3	411 ± 48	19.3 ± 0.6	40.1 ± 5.2	10.9 ± 0.4	3.9 ± 0.2	−16.1
	0	243 ± 17	8.0 ± 0.1	250.8 ± 18.2	4.6 ± 0.2	3.2 ± 0.2	−14.8
75/25	3	287 ± 8	14.7 ± 0.3	227 ± 11	6.9 ± 0.1	3.9 ± 0.1	−15.2
	0	–	–	–	–	–	–
80/20	3	218 ± 1	15.5 ± 0.1	342 ± 1.7	6.0 ± 0.7	4.1 ± 0.1	−15.1
	0	–	–	–	–	–	–
85/15	3	156 ± 4	14.0 ± 0.1	408 ± 25.9	5.3 ± 0.2	4.7 ± 0.1	−16.0
	0	142 ± 4	11.1 ± 0.2	401 ± 31.9	4.6 ± 0.2	4.5 ± 0.1	−15.5

[a] Yield stress and strain were measured with 1% offset following the ASTM D638.

[b] T_g was measured from the peak temperature of α-transition from the DMA spectrum.

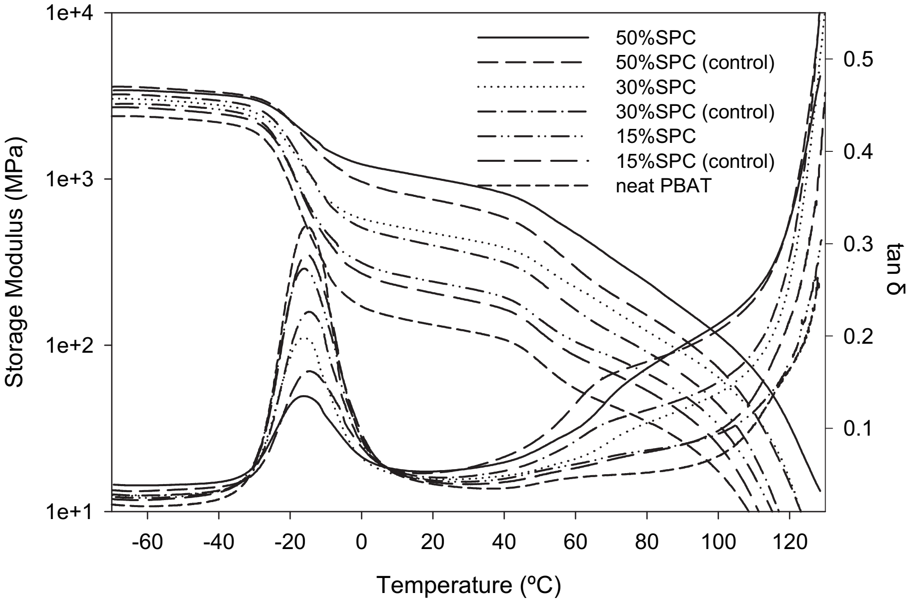

Fig. 9. Effects of SPC content and compatibilizer on dynamical mechanical properties of PBAT/SPC blends.

3.3. Tensile mechanical properties

The mechanical properties of a polymer blend strongly depends on its composition, interfacial adhesion and morphological structure. The stress–strain curves of the blends (Fig. 7) show a typical tensile behavior of polymer blends or composites composed of a rigid dispersed phase in a soft matrix with good interfacial adhesion. Tensile strength and modulus increased continuously with the increase of SPC content from 15 to 50%, while the strain at break monotonously decreased. Particularly, tensile properties exhibited more drastic changes when SPC content was higher than 25%. It is well accepted that the influences of filler content and phase structure of the blend could manifest more clearly in the changes of elastic modulus and mechanical properties at yield point. Fig. 8 clearly shows that the changes of modulus and yield stress and strain with SPC content experienced a transition at around 25% SPC. Modulus and yield stress of the blends demonstrated large changes when the SPC content was increased from 25 to 30% or higher, respectively, while the yield strain tended to level off thereafter. These results suggest that the critical loading level of SPC for the formation of percolated phase structure was around 25%, and it was consistent with the observations in above studies of morphology and rheology. However, uncompatiblized blends displayed drastically different behaviors. Table 1 gives the comparison of tensile properties of the compatiblized and uncompatibilized blends. The modulus of uncompatiblized blends still increased with SPC content but to a much smaller degree compared with that of the compatibilized ones. However, the change in tensile strength of uncompatibilized blends exhibited the opposite trend, showing continuous decrease with increasing SPC content. This significantly different behavior could be attributed to the effect of compatibilizer. The addition of compatibilizer resulted in fine phase structure, improved dispersion and interfacial adhesion.

3.4. Dynamic mechanical analysis

Dynamic mechanical properties of the blends are also greatly affected by phase structure. Fig. 9 compares the DMA results of neat PBAT and PBAT/SPC blends with and without compatibilizer. Neat PBAT displayed a major damping peak at −15.5 °C associated with a drastic drop in storage modulus (E′). Interestingly, it also showed a minor damping peak at 61 °C associated with a mild decrease in E′. This result suggests that although in general PBAT is considered as a random aliphatic–aromatic copolyester, it shows two glass transition regions with the one at lower temperature (T_{g1}) associated with the flexible aliphatic domain and the one at higher temperature (T_{g2}) with the rigid aromatic domain. The relative small drop in E′ corresponding to T_{g2} also indicates that the terephthalate monomer is minor in the copolyester. Similar observation of two T_gs for PBAT was also reported by Dacko et al. [34]. It was noted that T_{g1} of PBAT in the compatibilized blends was slightly lower than that in the uncompatibilized blends, and the latter was almost identical to T_{g1} of the neat PBAT. This result suggests that SPC was not miscible in PBAT at all even with the addition of PBAT-g-MA. The slight decrease in T_{g1} in the compatibilized blends was most likely due to incorporation of PBAT-g-MA into the matrix. T_{g2} of PBAT in the blends with and without compatibilizer showed a similar change to T_{g1}. Because T_{g2} of PBAT overlapped with the damping peak area of SPC phase [16], the values of T_{g2} of PBAT in the blends could not be properly identified from the damping peaks. On the other hand, the peak height of T_{g1} of PBAT in blends was substantially lower than that of the neat PBAT and continuously decreased with SPC loading level. The addition of compatibilizer further reduced the height of damping peak. Because the modulus of SPC was much higher than that of PBAT and SPC was largely in the glassy state in the testing temperature range, similar to other filler filled polymer systems [33], E′ of the PBAT/SPC blends was significantly higher than that of the neat PBAT and increased with SPC content in the whole temperature range. Obviously, compatibilized blends displayed higher E′ than uncompatiblized blends.

4. Conclusions

The phase morphology of PBAT/SPC blends was found to be greatly influenced by the combined effect of SPC content and compatibilizer. Without compatibizer, the SPC phase exhibited very coarse phase structure and large domain size. The addition of maleic anhydride grafted PBAT as compatibilizer resulted in fine morphological structure of the blends and elongated SPC domains which were observed to increase with SPC content. The formation of percolated SPC network structure was noted at 25% or higher SPC content as revealed by micrographs, dynamic rheological properties and mechanical properties of the blends. The percolated SPC structure greatly increased yield stress, tensile strength and elastic modulus but led to significant reductions in yield strain and strain at break. Dynamic mechanical properties of the blends are also greatly affected by the phase structure. Storage modulus of PBAT/SPC blends increased with SPC content and the addition of compatibilizer in the whole testing temperature range. Compatibilizer in blends was shown to be the prerequisite to obtain high performance PBAT/SPC blends.

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