

Elaboration, morphology and properties of starch/polyester nano-biocomposites based on sepiolite clay



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ABSTRACT

The incorporation of nano-sized sepiolite clays into thermoplastic starch/poly(butylene adipate-co-terephthalate) (TPS/PBAT) blends has been investigated with the goal of improving the matrix properties. TPS/PBAT nano-biocomposites were elaborated with two different proportions of the polymeric phases. The influence of the sepiolite nanoclays on the mechanical, thermal and structural properties of the corresponding blends was evaluated. SEM images confirmed the good dispersion of the sepiolite clay, with a low occurrence of small aggregates in the polymeric matrix. Wide-angle X-ray diffraction showed no significant alteration of the crystalline structures of PBAT and starch induced by the sepiolite clay. The addition of sepiolite slightly affected the thermal degradation of the nano-biocomposites; however, the mechanical tests revealed an increase in some mechanical properties, demonstrating that sepiolite is a promising nanofiller for TPS-based materials.

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1. Introduction

The inherent necessity to reduce the environmental pollution caused by plastic wastes has become a global concern, thereby motivating researchers to investigate environmentally friendly materials, with a focus on bio-based polymers as alternatives to the non-biodegradable plastics produced from fossil resources (Chivrac, Pollet, & Avérous, 2009; Avérous & Fringant, 2001). Starch is an inexpensive, biodegradable and abundant raw material, which are all attractive characteristics from commercial and environmental perspectives. To produce thermoplastic starch (TPS), native starch granules are processed under high temperature and shear conditions with the addition of plasticisers such as glycerol and water (Arvanitoyannis, Nakayama, & Aiba, 1998; Altskär et al., 2008; Van Soest, Hulleman, de Wit, & Vliegenthart, 1996).

Despite the great potential of TPS for applications in agricultural and packaging materials, its fragility and high sensitivity to moisture are limiting factors for materials made only of TPS. Hence, TPS is often blended with other polymers, such as PBAT, a biodegradable aliphatic-aromatic copolyester, which combines biodegradability and other desirable physical properties (Olivato et al., 2013; Park

et al., 2002). In addition to improving the biodegradation characteristics, starch can also reduce the cost of the final product compared to synthetics alone (Dean, Yu, & Wu, 2007; Wilhelm, Sierakowski, Souza, & Wypych, 2003).

The morphology of multiphase systems such as blends is influenced by the processing conditions, the miscibility and viscosity of the polymer phases, and by the amounts of each phase in the final mixture. These are the determining characteristics for the performance of starch-based materials (Schwach & Avérous, 2004).

Combining TPS with nanofillers to produce nanocomposites, with the aim of enhancing the mechanical, thermal and barrier properties of the polymeric matrix, is currently the focus of numerous studies (McGlashan & Halley, 2003; Ray & Okamoto, 2003; Bordes, Pollet, & Avérous, 2009; Avérous & Pollet, 2012). Nanofillers based on natural clay minerals are one of the best options to improve the biodegradable polymer matrix properties due to their easy availability, versatility, and their low environmental and health concerns (Chang, Wu, Anderson, & Ma, 2012). The properties of the corresponding multiphase systems (so-called nano-biocomposites) are strongly dependent on the amount of nanofiller and its dispersion state. The improvement in the mechanical properties with the inclusion of nanofillers is primarily a result of good dispersion and strong polymer–filler interactions (Duquesne, Moins, Alexandre, & Dubois, 2007; Chen, Zheng, Sun, & Jia, 2007).

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Taking its many advantages into account, sepiolite nanoclay, a hydrated magnesium silicate with a microfibrillar morphology (needle-like shape) and a particle size ranging between 10 and 5000 nm long, 10 and 30 nm wide, and 5 and 10 nm thick, was considered in this study. Its structure is based on alternating blocks and tunnels ($0.36 \text{ nm} \times 1.1 \text{ nm}$) that grow in the fibre direction. The discontinuity of the silica sheets gives rise to the presence of silanol groups ($\text{Si}-\text{OH}$) at the edges of the tunnels opened at the surface of the sepiolite particles (Duquesne et al., 2007; Darder et al., 2006; García-Lopez, Fernández, Merino, Santarén, & Pastor, 2010). The sepiolite clay is rather compatible with starch because its silanol groups form hydrogen bonds with the hydroxyl groups of starch (Chivrac, Pollet, Schmutz, & Avérous, 2010). A better clay dispersion can thus be expected, consequently improving the mechanical properties of the polymer nano-biocomposites (García-Lopez et al., 2010; Bilotti et al., 2009).

With the aim of producing efficient starch-based materials, this study investigated the structure/property relationships of TPS/PBAT blends and their corresponding sepiolite-based nano-biocomposites. The mechanical, thermal and structural properties of these materials were evaluated.

2. Experimental

2.1. Materials

Nano-biocomposites were produced with native cassava starch (amylose $20.8 \pm 0.6 \text{ wt\%}$; protein $0.28 \pm 0.1 \text{ wt\%}$; lipids $0.11 \pm 0.6 \text{ wt\%}$; ash $0.22 \pm 0.6 \text{ wt\%}$, db) obtained from Indemil (Paranavaí, Brazil), glycerol (99.5% purity) kindly supplied by Novance (Paris, France) and PBAT (poly(butylene adipate-co-terephthalate)) supplied by BASF (Ludwigshafen, Germany) under the commercial name Ecoflex®. Neat sepiolite, also known as natural or sodium sepiolite (S), is a commercial clay with a cation-exchange capacity (CEC) of $150 \mu\text{equiv/g}$, and it was supplied by Tolsa (Madri, Spain) under the trade name Pangel® S9.

2.2. Thermoplastic starch (TPS) preparation

As the first step, starch/glycerol dry-blends were prepared. In this process, native cassava starch was dried overnight at 70°C in a ventilated oven. The dried starch was then introduced in a turbo-mixer, and glycerol was slowly added while stirring at 1700 rpm until a homogenous mixture was obtained. The mixture was dried at 170°C in a ventilated oven for 40 min, and then the dry-blend was recovered and stored in a sealed plastic bag. To obtain TPS, the dry-blend was processed, with the addition of water, in a Rheomix OS (Haake, USA) counter-rotating internal batch mixer at 70°C for 20 min with a rotor speed of 150 rpm, resulting in a formulation containing 54 wt% cassava starch, 23 wt% glycerol and 23 wt% water. TPS/sepiolite nano-biocomposites and a master-batch (TPS + 10 wt% sepiolite) were also produced using the same processing conditions with the incorporation of the appropriate amount of sepiolite clay into the TPS.

2.3. Production of blends and nano-biocomposites

The different blends (TPS/PBAT) and nano-biocomposites were produced by mixing in a Rheomix OS (Haake, USA) counter-rotating internal batch mixer at 130°C for 20 min and 150 rpm. The mixtures were then compression moulded (Labtech Engineering Company, Muang, Thailand) at 130°C for 12 min with a pressure of 20 MPa. Two TPS/PBAT proportions were tested, 50:50 and 80:20, with 0, 1, 3 or 5 wt% of sepiolite clay. The corresponding samples were designated as XX/YY/Z, where X is the proportion of TPS, Y is the proportion of PBAT in the blend, and Z is the wt% of sepiolite clay.

Reference materials based on neat TPS or PBAT with 3 wt% sepiolite were also produced. All of the samples were conditioned at a $53 \pm 2\%$ relative humidity and $25 \pm 2^\circ\text{C}$ for 20 days to obtain stabilised samples before the analysis and to take into account the post-processing aging of these materials.

2.4. Characterisation

2.4.1. Mechanical properties

The tensile strength, elongation-at-break and Young's moduli were determined according to ASTM D638-03 using a Universal Testing Machine MTS 2/M (Minnesota, USA) at a strain rate of 50 mm/min at 20°C .

2.4.2. Scanning electron microscopy (SEM)

A FEI Quanta 200 scanning electron microscope (FEI Company, Tokyo, Japan) was used to observe the cryogenic fractured surfaces of the samples. The materials were stored at 25°C in a desiccator with CaCl_2 ($\approx 0\%$ RH) for 3 days and then coated with a gold layer using a sputter coater (BAL-TEC SCD 050). The images were taken at magnifications of $2000\times$ and $4000\times$.

To observe the morphologies of the samples by SEM, the 50/50/0 and 80/20/0 systems were subjected to solvent extraction. For the 50/50/0 sample, the TPS phase was selectively extracted by stirring the sample at room temperature for 4 h in a solution of DMSO/HCl (8 M). For the 80/20/0 sample, the PBAT phase was extracted with chloroform using similar conditions. After drying, the samples were subjected to the previously described treatments before performing the SEM imaging.

2.4.3. Thermogravimetric analysis (TGA)

The thermal stability of the different materials was determined by TGA using a Q5000 instrument (TA Instruments, New Castle, USA); samples of approximately 5 mg were heated from 25°C to 700°C at $20^\circ\text{C}/\text{min}$ under an air atmosphere (flow rate of $10 \text{ ml}/\text{min}$).

2.4.4. X-ray diffraction (XRD)

X-ray diffraction (XRD) analysis was conducted using a D8 Advance (Bruker, Massachusetts, USA) diffractometer with a $\text{CuK}\alpha$ radiation source ($\lambda = 0.1546 \text{ nm}$) operating at 40 kV and 40 mA. The samples were scanned over a 2θ range from 5 to 50° at a scan rate of $0.9^\circ/\text{min}$.

2.4.5. Melt viscosity analysis

The data recorded during the mixing (torque values vs residence time) in the internal batch mixer were used to evaluate the melt viscosity of the multiphase systems under thermo-mechanical treatment.

2.4.6. Statistical analysis

The data were analysed using STATISTICA 7.0 software (Statsoft, Oklahoma), with analysis of variance (ANOVA) and Tukey's test at a 5% significance level.

3. Results and discussion

3.1. Melt viscosity analysis

The torque vs residence time curves were recorded during the processing of TPS/PBAT blends and are shown in Fig. 1. All the nano-biocomposites showed an increase in the torque value at the beginning of the process, which corresponds to the melting of PBAT and TPS. The addition of sepiolite altered the viscosity of the samples, leading to higher torque values with increased

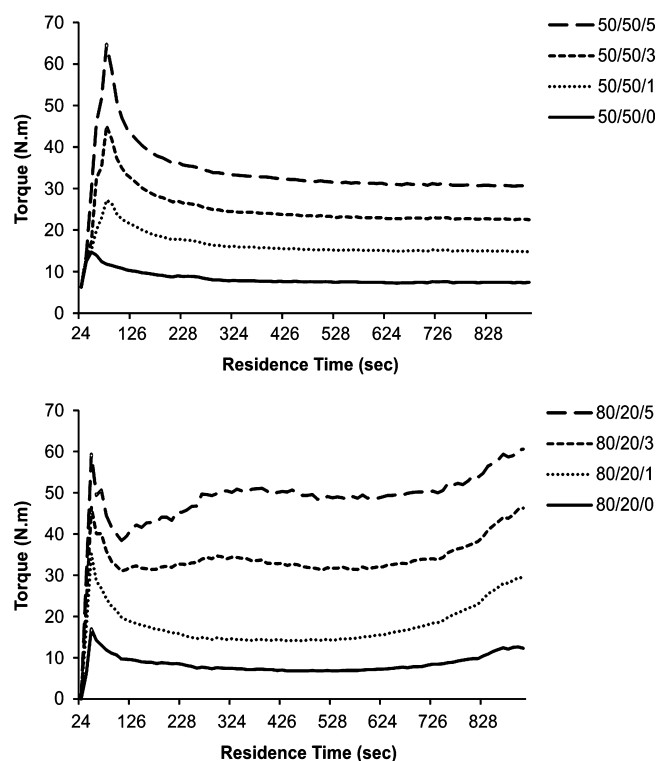


Fig. 1. Torque curves recorded during the elaboration of the nano-biocomposites.

nanoclay content. Because sepiolite clay has a needle-like morphology, it behaves differently than layered clays. Montmorillonite platelets tend to present some flow orientation and could result in a decrease in the matrix viscosity, in the melting state, under thermo-mechanical treatment. Based on their needle-like structures, the sepiolite particles acted as anchoring points and limited the chains' motion. This phenomenon could explain the increase in the torque values for the nano-biocomposites observed in the melt viscosity analysis.

After ca. 400 s, a stabilisation of the torque value occurred for the 50/50 blends. However, for the 80/20 blends, the torque continued to increase throughout the processing, and the increment was dependent on the concentration of nanofiller. This behaviour cannot be fully explained by the plasticiser lost during the mixing because such a phenomenon did not occur with the other materials based on 50% TPS.

Interestingly, Chang et al. (2012) observed that sodium rectorite clay treated with cationic guar gum increased the viscosity of the TPS matrix because this clay is capable of forming strong interactions with starch chains. Considering the large number of silanol

groups at the sepiolite surface, the numerous interactions with starch chains can also explain the increase in torque during the processing for the 80/20-blend-based materials.

3.2. Mechanical properties

Table 1 shows the mechanical properties for all of the samples. TPS with a high plasticiser content (23 wt% glycerol and 23 wt% water) and without additives and/or modification of the matrix is characterised by a low modulus and tensile strength. The addition of 3 wt% sepiolite (TPS/S) resulted in an increase in both the Young's modulus (over 300%) and the tensile strength (150%) while maintaining the elongation-at-break values of the TPS materials. Chivrac et al. (2010) observed similar results with the incorporation of natural sepiolite (3 wt%) in thermoplastic wheat starch, supporting the good performance of this nanoclay in starch-based materials.

A slight increase in the Young's modulus and tensile strength was observed with 3 wt% sepiolite in the PBAT matrix, which also resulted in a reduction of the elongation-at-break value for the PBAT/S material. This behaviour could be due to interactions between the carbonyl groups of PBAT and the hydroxyl groups of the sepiolite clay, as previously stated by Fukushima, Wu, Bocchini, Rasyda, and Yang (2012a).

Considering the 50/50 TPS/PBAT nano-biocomposites (Table 1), higher amounts of sepiolite did not influence the tensile strength of the materials but did result in stiffer samples, with the Young's modulus reaching 117.1 ± 5.3 MPa with the addition of 5 wt% sepiolite (50/50/5). A marked decrease in the elongation-at-break value was also observed for these materials, likely due to the presence of some clay aggregates.

For the nano-biocomposites produced with 80/20 TPS/PBAT blends (Table 1), the addition of sepiolite increased the matrix stiffness (higher Young's moduli). A reinforcement effect was also observed for these nano-biocomposites, with a slight increment in the tensile strength according to the sepiolite content. No significant variation in the elongation-at-break was observed, even with a high sepiolite content (5 wt%). This absence of material embrittlement with increased sepiolite content appears to indicate a good affinity and high dispersion of the nanoclay in the TPS-rich materials.

The mechanical properties suggest that sepiolite is more compatible with the TPS phase due its more hydrophilic character and is thus preferentially localised in this phase. A higher TPS content therefore facilitates the dispersion of sepiolite and its relative contribution to the final mechanical properties. With the increase in PBAT content (50/50 blends), sepiolite was mostly localised to the TPS phase, and because the TPS content was reduced, the dispersion of the nanofillers became more difficult and contained more aggregates. Such morphology negatively impacts the mechanical properties.

Table 1
Mechanical properties of TPS, PBAT and the corresponding blends and nano-biocomposites based on sepiolite clay.

Sample	Tensile strength (MPa)	Elongation at break (%)	Young's modulus (MPa)
TPS	2.3 ± 0.4	55.7 ± 20.3	51.7 ± 11.1
TPS/S	3.6 ± 0.6	60.0 ± 15.4	179.2 ± 50.9
PBAT	12.7 ± 0.5	> 600	41.0 ± 1.3
PBAT/S	14.0 ± 1.1	569.7 ± 30.1	57.9 ± 3.6
50/50/0	6.2 ± 0.2^a	284.1 ± 16.6^a	52.4 ± 1.1^d
50/50/1	5.3 ± 0.1^a	120.5 ± 17.2^b	58.0 ± 2.1^c
50/50/3	5.4 ± 0.2^a	54.9 ± 17.2^c	69.5 ± 2.3^b
50/50/5	5.6 ± 0.3^a	15.1 ± 1.7^d	117.1 ± 5.3^a
80/20/0	3.2 ± 0.2^b	37.1 ± 2.4^a	49.2 ± 0.7^c
80/20/1	3.2 ± 0.1^b	25.6 ± 1.9^a	$72.2 \pm 4.7^{b,c}$
80/20/3	$3.4 \pm 0.2^{a,b}$	25.4 ± 2.0^a	$82.3 \pm 7.9^{a,b}$
80/20/5	4.0 ± 0.1^a	27.8 ± 5.7^a	102.1 ± 4.2^a

^{a,b,c,d} Means in the same column with different letters differ significantly, considering the same proportions of the polymeric phases (Tukey's test; $p < 0.05$).

Table 2

Degradation temperatures for TPS, PBAT and the nano-biocomposites obtained by TGA analysis.

Samples	Degradation temperatures (°C)				
	Water	Glycerol	Amylose	Amylopectin	PBAT
TPS	174.1	282.6	314.1	358.1	–
TPS/S	163.3	287.9	312.9	360.5	–
PBAT	–	–	–	–	439.0
PBAT/S	–	–	–	–	437.5
50/50/0	163.1	315.6		346.1	432.8
50/50/5	158.1	–		345.3	432.2
80/20/0	169.2	292.5		353.1	435.2
80/20/5	181.5	–		357.9	439.8

Considering the mechanical properties of the materials, it is possible to highlight the great potential of sepiolite compared to montmorillonite clay, as the needle-shaped morphology of sepiolite results in significantly higher Young's modulus and tensile strength values compared to the corresponding montmorillonite nano-biocomposites, as previously studied by [Nayak \(2010\)](#).

3.3. Thermogravimetric analysis (TGA)

The degradation temperatures of neat PBAT, TPS and the corresponding blends and nano-biocomposites were determined by TGA ([Fig. 2](#) and [Table 2](#)).

For the pristine TPS matrix, four different degradation steps are observable. The first two steps correspond to the loss of water and

glycerol, and the final two steps correspond to the thermal degradation of amylose and amylopectin ([Nayak, 2010](#)). As shown in the derivative weight loss curves (DTG), the starch degradation temperature for neat TPS at 358 °C is slightly shifted towards higher temperatures (360 °C) in the presence of 3 wt% sepiolite (TPS/S samples), demonstrating that the addition of sepiolite slightly increases the thermal degradation temperature of the TPS matrix ([Table 2](#)). [Chivrac et al. \(2010\)](#) reported similar results, in which the degradation temperature of neat TPS was increased from 318 °C to 321 °C with the incorporation of 3 wt% sepiolite clay.

Neat PBAT exhibits a single degradation step with a degradation temperature of 439 °C, without significant changes resulting from the incorporation of 3 wt% of sepiolite, as 438 °C was recorded for this sample ([Fig. 2](#)). Considering the assumption that sepiolite is more compatible with the TPS phase, it could be expected that its contribution to thermal properties is more pronounced with this matrix.

Hydrophobic nanoclays such as organically modified MMT (Cloisite® 30B) were evaluated by [Mohanty and Nayak \(2012\)](#) and were found to improve the thermal stability of PBAT due their ability to act as a heat barrier and to assist in char formation during thermal decomposition ([Ray & Okamoto, 2003](#)).

Samples 50/50/0 and 80/20/0 ([Table 2](#)) each show four degradation steps, which are a combination of the steps observed for neat PBAT and TPS. In these samples, a single peak at approximately 350 °C was observed as a coalescence of the peaks corresponding to the degradation temperatures of amylose and amylopectin. The addition of 5% sepiolite (50/50/5 and 80/20/5) slightly affected the thermal degradation of the nano-biocomposites, specifically eliminating the thermal degradation at approximately 300 °C that corresponds to the loss of water and glycerol loss. This observation may be due to some interaction between glycerol and the hydroxyl groups of the sepiolite clays.

The increase in the degradation temperatures for the nano-biocomposites with the addition of 5 wt% sepiolite was more evident for the 80:20 TPS/PBAT blend due to the enhanced dispersion of sepiolite in the more abundant TPS-rich phase.

These results are in good agreement with those reported by [Nayak \(2010\)](#), who studied the impact of organo-modified montmorillonites and found that the presence of clay increased the degradation temperatures of PBAT/TPS blends.

3.4. Scanning electron microscopy (SEM)

[Fig. 3](#) shows the SEM images for the 50:50 and 80:20 TPS/PBAT blends after selective extraction of the TPS and PBAT phases, respectively. Previous studies reported that co-continuity occurs at the phase inversion point when the proportions of the polymeric phases are approximately equal. However, the influence of the interfacial tension, the shape of the dispersed component and the process conditions (such as stress level and matrix viscosity)

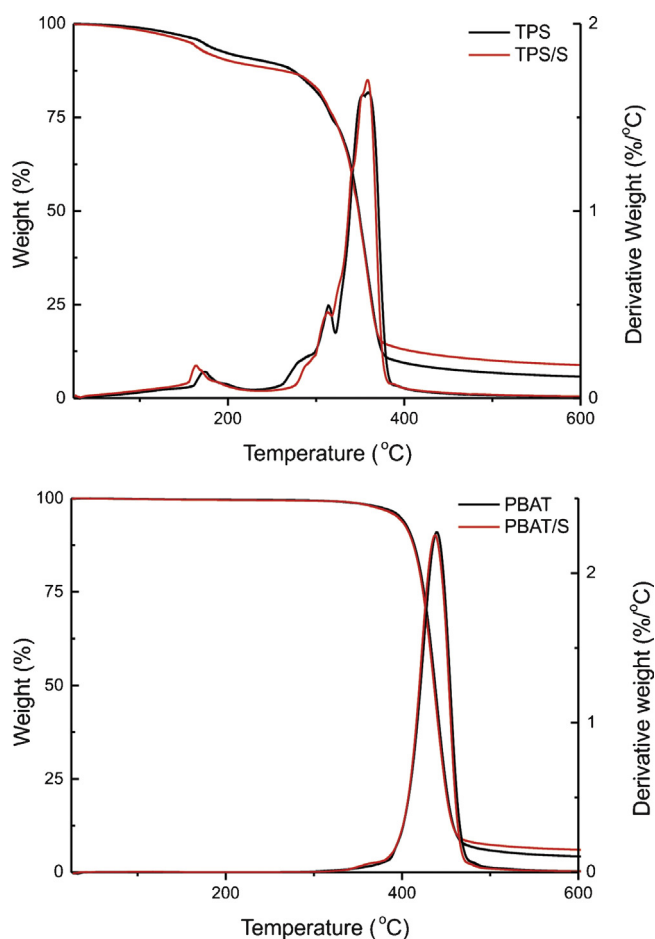


Fig. 2. TG and DTG curves for TPS and PBAT reference materials and TPS/S, PBAT/S containing 3 wt% sepiolite clay.

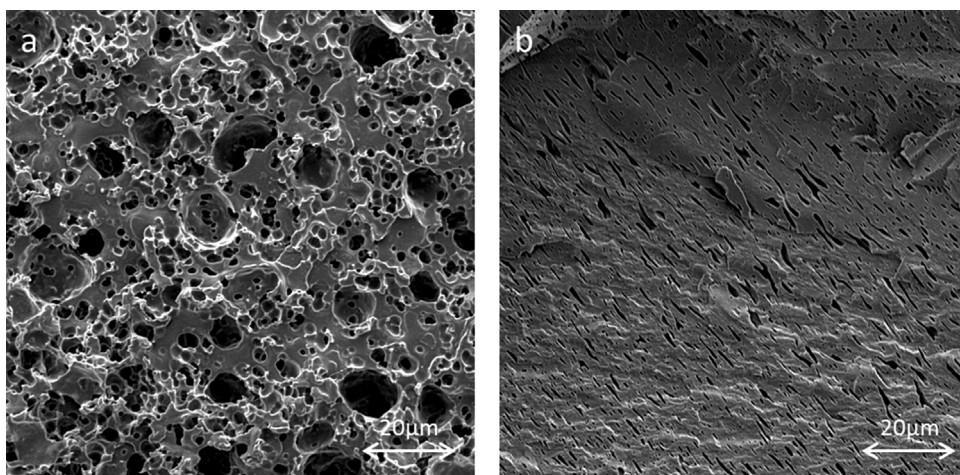


Fig. 3. SEM images of the fracture surfaces of samples 50/50/0 (a) and 80/20/0 (b) after selective phase extraction. Magnification 2000 $\times$. Scale bars = 20 μ m.

are also quite important for obtaining a co-continuous structure (Willemse, de Boer, van Dam, & Gotsis, 1999; Walia, Lawton, Shogren, & Felker, 2000; Schwach & Avérous, 2004).

Contrary to the expected co-continuity at equal proportions of the polymeric phases, materials with equal proportions of TPS and PBAT (50/50/0) were found to have a disperse morphology, with spherical TPS domains, suggesting that for this material, the co-continuity will likely occur for greater proportions of TPS. In addition to the previously cited influence of processing conditions, the critical role of water in the morphology of TPS/polyester blends was analysed by Walia et al. (2000), who demonstrated that the onset of co-continuity could shift to higher disperse phase concentrations depending on the moisture content, in agreement with the behaviour observed for the blends in this work.

For the 80/20/0 samples, a disperse phase of PBAT was observed. Comparing the mechanical properties of this material with those of the 50/50/0 sample, lower tensile strength and elongation-at-break values were observed, which resulted from the morphologies of the immiscible blends. In this case, the disperse phase, formed by PBAT, is encapsulated by the TPS phase, which has a higher viscosity in the melting state during processing. The corresponding mechanical properties of the blend are therefore mainly driven by those of TPS because the continuous phase is responsible for absorbing stress under loading (Schwach & Avérous, 2004).

The addition of sepiolite nanofiller did not affect the morphology of the TPS/PBAT blends, as shown at Fig. 4. In this image, it is possible to observe the round disperse phase composed of TPS and the continuous phase composed of PBAT in the 50/50/5 sample. For the

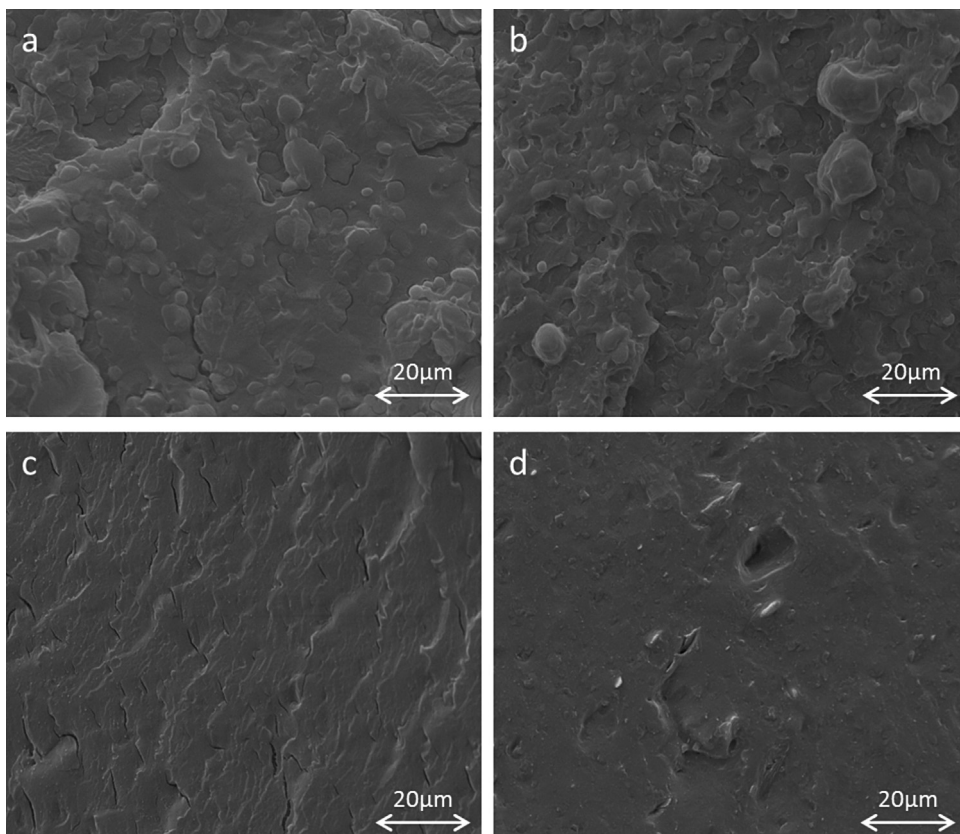


Fig. 4. SEM images of the fracture surfaces of samples 50/50/0 (a); 50/50/5 (b); 80/20/0 (c) and 80/20/5 (d). Magnification 2000 $\times$. Scale bars = 20 μ m.

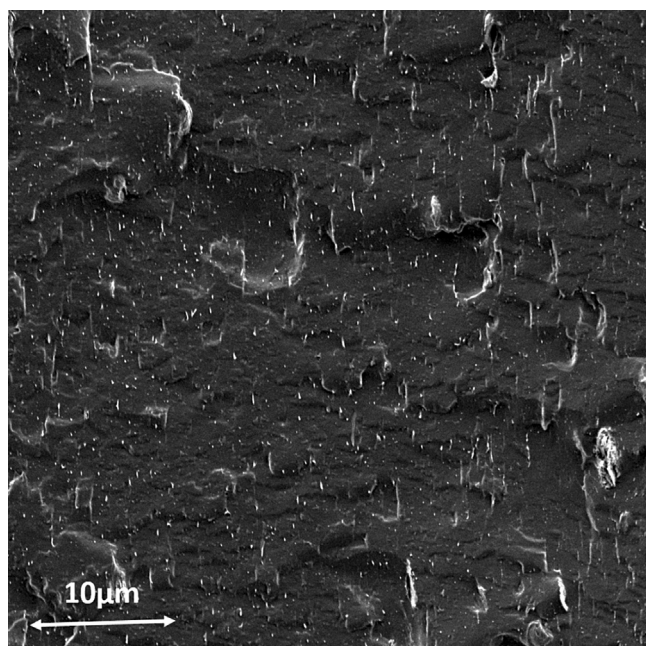


Fig. 5. SEM image of the fracture surface of the 80/20/5 sample showing the sepiolite dispersion in the matrix. Magnification 4000 $\times$. Scale bar = 10 μ m.

80/20/5 sample, the structure appears to be more homogeneous due to the higher proportion of TPS. The white spots represent the sepiolite clay particles, which are more evident for the 80/20/5 nano-biocomposites (Fig. 4d).

A detailed micrograph of the 80/20/5 sample (Fig. 5) shows a good dispersion of sepiolite clay, with a low occurrence of small aggregates in the polymeric matrix. This morphology is in agreement with the determined mechanical and thermal properties. A good sepiolite dispersion was also observed by SEM by Bilotti et al. (2009) for polyamide 6/sepiolite. Fukushima, Fina, Geobaldo, Venturello, and Camino (2012b) also presented SEM images with visual dispersions of the sepiolite clay similar to those reported in this work.

3.5. X-Ray diffraction (XRD) analysis

Fig. 6 shows the XRD patterns recorded for the blends and the 50/50/1, 50/50/3 and 50/50/5 nano-biocomposites. The nano-biocomposites based on the 80:20 TPS/PBAT blend showed similar patterns (not shown here), except with lower intensities for the peaks corresponding to the PBAT crystalline structure because this phase has a lower content in these materials.

The peak at $2\theta = 7.3^\circ$ is assigned to the (1 1 0) plane of the sepiolite clay and increases in intensity as the amount of nanofiller increases, without changes in the 2θ values. These data are in accordance with those reported by Tartaglione, Tabuani, Camino, and Moiso (2008), who showed that the dimension of the channels present in the sepiolite clay could not be affected by the melt-blending process. Because the structural layers of sepiolite are joined by covalent bonds, the interlayer distance is fixed. The clay does not present swelling properties, and the clay layers cannot be individually delaminated as is commonly observed for montmorillonite. For this reason, XRD is not the best tool to discuss the dispersion quality of sepiolite in the polymeric matrix; however, it can provide some information about possible changes in the crystalline structures of the polymeric phases.

The process-induced crystallisation of starch (type V_H) is responsible for the peaks observed at $2\theta = 13.2^\circ$ and 20.2° (Olivato et al., 2013; Van Soest et al., 1996). The PBAT crystalline structure

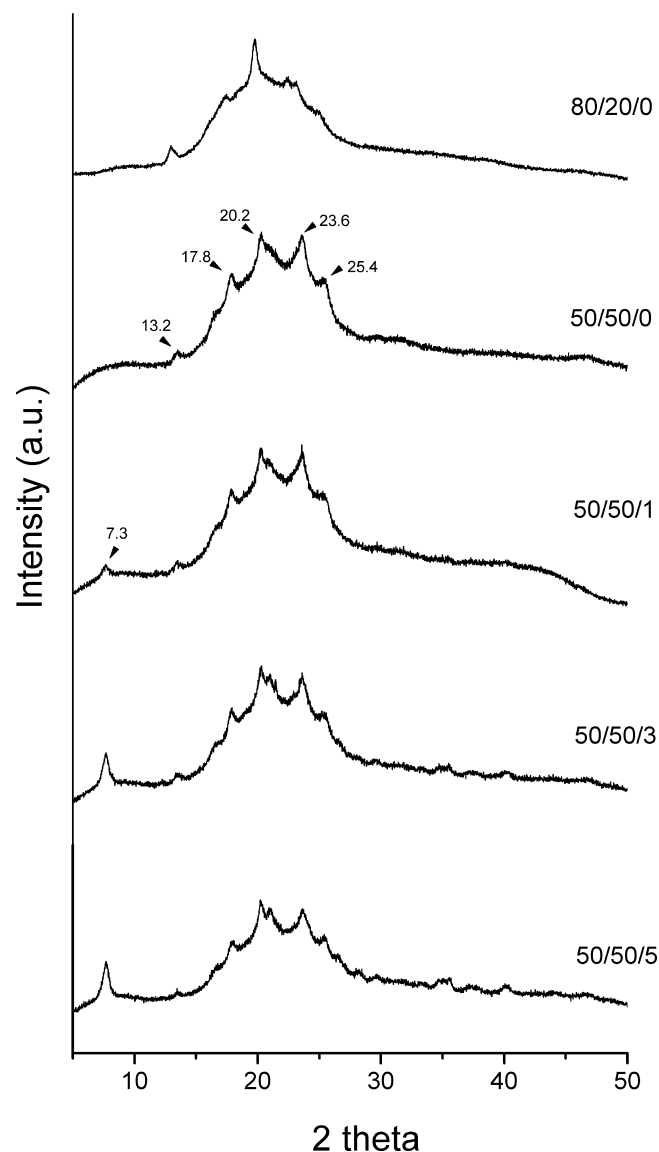


Fig. 6. XRD patterns of different TPS/PBAT nano-biocomposites.

produces the peaks observed at $2\theta = 17.8^\circ$, 23.6° and 25.4° (Raquéz, Nabar, Narayan, & Dubois, 2008). These five peaks, corresponding to $2\theta = 13.2^\circ$, 17.8° , 20.2° , 23.6° and 25.4° , are still observed for all the nano-biocomposites without differences in the peaks' positions or intensities. This result confirms the absence of significant changes in the crystal structures of PBAT and starch due to the addition of nanofiller. This result is also consistent with the results obtained by Chivrac, Kadlecová, Pollet, and Avérous (2006), who observed no effect of the addition of MMT nanofiller on the crystallinity of the PBAT matrix.

4. Conclusion

Sepiolite clays were found to be efficient in improving the mechanical and thermal properties of starch/PBAT blends. The use of this nanoclay represents an interesting route to produce more resistant starch-based materials because the inclusion of sepiolite resulted in an important enhancement of the mechanical properties of TPS, reaching a 300%-increase in the Young's modulus and a 150%-increase in tensile strength with the addition of 3 wt% sepiolite to the TPS matrix.

Due the presence of silanol groups at the surface of the sepiolite, strong hydrogen-bonding interactions form with the starch hydroxyl groups. Their contribution to the mechanical and thermal properties was more pronounced for materials with higher TPS contents (80/20 TPS/PBAT samples).

Scanning electron microscopy images showed a good dispersion of the sepiolite in the samples, which is important for attaining better performance materials. The images also showed no effect of sepiolite on the morphology of the TPS/PBAT blends. Furthermore, samples produced with equal proportions of TPS and PBAT showed a dispersive blend, with round TPS domains, and for the 80:20 TPS/PBAT samples, a dispersed phase of PBAT was observed.

Interestingly, the recent literature appears to indicate that the behaviour of sepiolite is closer to that of natural organic rod-like cellulose nanowhiskers than to inorganic lamellar nanoclays. These bio-based multiphase materials could represent an interesting alternative to some non-biodegradable plastic materials for applications related to short-term packaging, agriculture or biomedicine.

Further specific experiments will be performed to better understand and describe the mechanisms involved in the melt mixing with an increase in the viscosity at high TPS content.

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