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# Evaluation of Styrene Content over Physical and Chemical Properties of Elastomer/TPS-EVOH/Chicken Feather Composites

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## Abstract

A series of styrene-butadiene (SB) elastomer/thermoplastic starch (TPS)/ethylene vinyl alcohol copolymer (EVOH) composites were modified including chicken feathers in its formulation, which have the main component keratin. The composites were prepared by means of melt blending, and their chemical interactions were evaluated by means of infrared spectroscopy (FTIR), and their thermal properties as Tg values were investigated using differential scanning calorimetry (DSC), thermal stability using thermogravimetric analysis (TGA), and viscoelastic properties with dynamic mechanical analysis (DMA). The styrene content in SB was changed in 3 levels, and chicken feather content also changed in 3 levels. It was identified that Tg value in composites decreases that is attributed to the styrene content in elastomer and that the chicken feather improved the storage modulus of composite. The thermal stability of composites also was affected by the presence of chicken feathers due its good thermal properties.

**Keywords:** styrene-butadiene copolymer (SBR), EVOH, thermoplastic starch (TPS), chicken feather (CF), thermal behavior

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## 1. Introduction

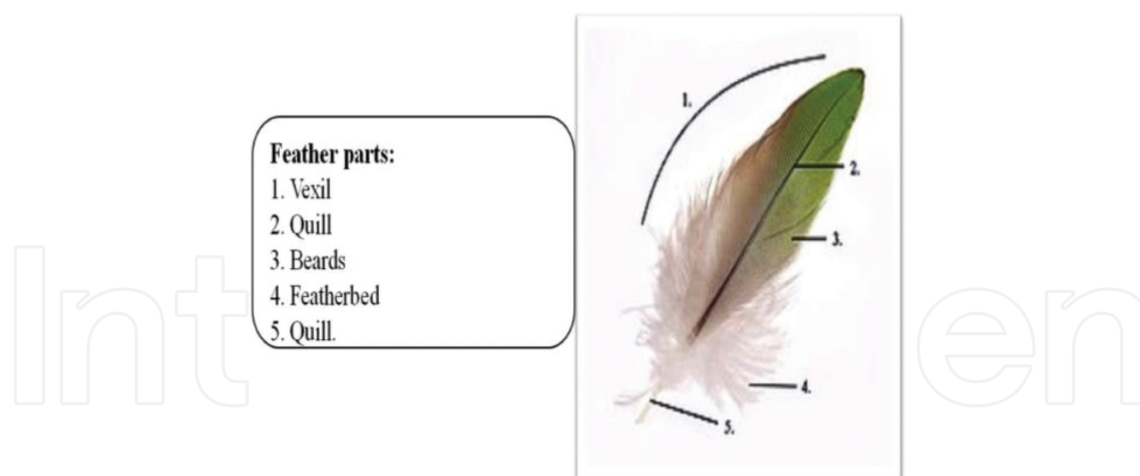
The poor disposition of solid wastes from natural resources that adversely affect the environment has developed interest related to the development of biodegradable polymers to obtain

improved composites, not only for environmental reasons but also for their properties and sustainability [1–3]. A valuable alternative with enormous potential is to manufacture composite materials using chicken feather (CF). Keratin is the main component of CF that has extraordinary properties of thermal and mechanical resistance, is also light and confers acoustic insulation, and is a light material with high mechanical and thermal resistance, and for some decades, it was the focus of attention to be used as a raw material in combination with different plastics products [4–12]. The CF that generates the poultry industry as solid waste represents more than five million tons per year. Recently, the literature points the keratin of CF as a material with low cost by its abundance in the nature and that can take advantage of the waste of the birds, which confers a status of material recycled environment friendly [10]. According to previous works, keratin can be used in conjunction with other biomaterials in medical applications suggesting affinity with cells and tissues, also in combination with other biopolymers as chitosan [13]. In addition, chicken feather keratin is a renewable and low-cost material [14–20] and is compatible with biodegradable polymers as chitosan-starch [21], cellulose, wool [4], including thermoplastic starch (TPS) [14–20] and ethylene vinyl alcohol copolymer (EVOH), which provides greater ductility and improves the elasticity of TPS. In nature, natural fibers are obtained with good physicochemical properties such as keratin, which is extracted from nature and can also be found in nails, wool, claws, horns, and feathers [8, 22]. Research has focused in conjunction with manufacturers in finding new directions for the application of keratin in polymer blends which have not been well known to the present. According to Cheng et al. [23], the feasibility of using the fiber of chicken feathers in compounds with polylactic acid (PLA) has been studied in terms of its mechanical and thermal properties. To test the mechanical and physical properties of the panels, Winandy et al. [8] have materialized a series of medium-density fiber panels containing several different blends of wood fiber and chicken feather fiber (CFF). **Figure 1** shows the constituents of a chicken feather.

Barone and Schmidt [24] reported the use of feather keratin fiber as a short fiber reinforcement in low-density polyethylene composites. Research has been reported on high-density polyethylene-based compounds using keratin from chicken feathers. Taking into account the hydrophilic properties of keratin, its potential application in the manufacture of fibers with improved sorption characteristics is seen, being useful for the production of textile material that focuses on sanitary and medical applications.

In previous works [3], chicken feather keratin fibers were used as reinforcement in the poly(methylmethacrylate) (PMMA) matrix. The composites were evaluated by thermal and dynamic-mechanical analysis. The high-temperature stability and thermal transition of the keratin/PMMA base compound were found to be higher than that of virgin PMMA.

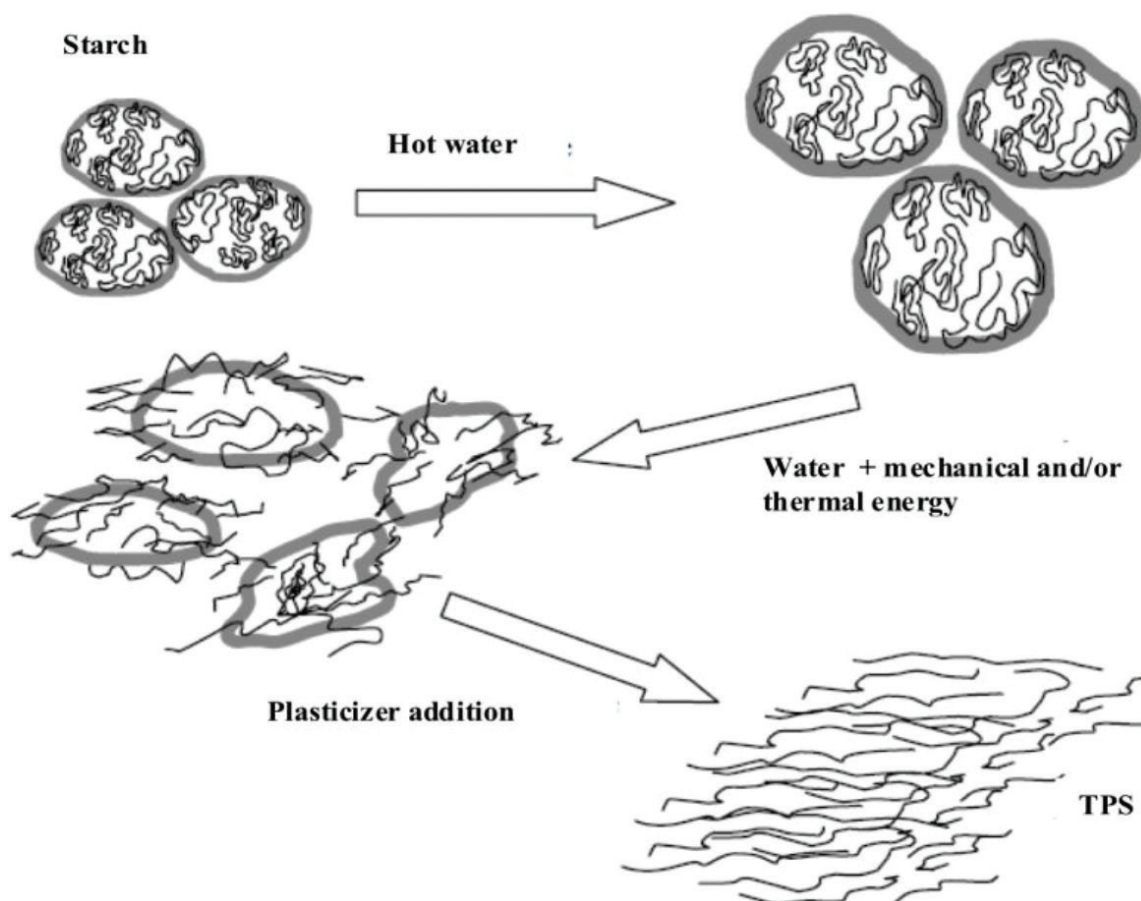
Villarreal-Lucio et al. [25] prepared composites from chicken feathers and polyvinyl chloride (PVC) finding that composites CF-PVC represent an opportunity to obtain materials with improved properties such as thermal stability and dynamic-mechanic properties, but with a low interfacial addition between PVC and CF. Starch is a biopolymer obtained from renewable plants such potato, maize, wheat, and others sources. The main components are amylose and amylopectin, the first one is a linear polysaccharide and second one has a branched structure.



**Figure 1.** Constituents of a chicken feather.

It is a cheap material compared with synthetic polymers in packing applications. The TPS refers to granule starch, which has been deconstructed, forming a mixture of its polymer constituents and various proteins, lipids, and smaller molecules that are also contained in the starch granule. With the aim to improve its processability and mechanical properties and moisture resistance, starch is blended by extrusion with other polymers, using plasticizers as glycerin and water. In this way, it is possible to obtain a material with desired physical properties [26]. The transformation of native starch to thermoplastic starch (TPS) by extrusion results in the loss of the natural chain structure. That is, processing in the presence of heat and water causes the starch granules to gel or break, progressively destroying crystallinity [26]. Starch has been used as a thermoplastic material because it is a renewable, biodegradable, and very low-cost resource [21]; the most effective plasticizer for starch-based materials is glycerol, water, sorbitol, and urea [26]. To improve the properties of thermoplastic starch (TPS) because it is not a good choice because of its poor mechanical properties and because of its susceptibility to moisture, the structure of the starch has been modified, mixed with other polymers (biodegradable and/or synthetic), and a better interfacial adhesion is obtained with compatibilizers. **Figure 2** shows the process of gelatinization and plasticization for starch [27].

One of the thermoplastic materials compatible with TPS is EVOH, which is widely used in the food packaging industry. It is a biodegradable polymer and considered a good compatibilizer that when added to a mixture of immiscible materials during the extrusion modifies the interfacial properties and stabilizes the mixture. It is known that EVOH provides it a better ductility and improves the elasticity of TPS [26]. Several researches have been carried out with TPS-EVOH composites reinforced with natural biopolymers, and among others are coir, cellulose fibers [15, 16], and hydroxyapatite [17–19], but there are no reports where CF is used as a reinforcer in TPS/EVOH composites. Several studies have been carried out on the composite materials using SB elastomers and keratin from the CF, which has allowed knowing about the influence of the different variables on the thermal and mechanical behavior, as well as the various valid tools for the observation of variations [2, 9, 20, 28–30]. With respect to



**Figure 2.** Gelatinization and plasticization of starch.

the above, several important aspects are listed namely dynamic-mechanical behavior, hydrophilic, acoustic, and thermal stability properties of keratin, and its study per se represents a vast field of scientific exploration. In the other hand, the use of elastomers in combination with other materials as compound has been reported, trying to improve ductility and oxygen barrier of elastomers [31–33]. Among the elastomers, the styrene-butadiene (SB) copolymers are the most valuable due to the wide application areas as adhesives, asphalt modifiers, sealants, shoe soles, impact modifiers, and also can be compounded to produce materials that enhance grip, feel, and appearance in applications such as tires, automotive parts, and packing [34, 35]. SB copolymers are considered a thermoplastic material, whose elastic behavior<sup>1</sup> and thermoplastic behavior<sup>2</sup> are combined at same time. The combination of good mechanical properties and processability makes the SB copolymers an interesting kind of materials. It is essential that hard (styrene block) and soft (butadiene) segments are immiscible on a microscopic scale. One important variable is SB copolymer properties, the styrene content, which gives a plastic characteristic to copolymer with high styrene content, and elastomer behaves as a vulcanized elastomer at low styrene content. Because of its good processability behavior, thermal, and mechanical properties, SB copolymers have been widely used in composite materials, trying

<sup>1</sup>Property to change and recover the shape when a force has applied and then removed.

<sup>2</sup>The property to become viscous and free-flowing liquid when heated and resolidified when cooled to room temperature.

Material	Elastomer (g)	TPS-EVOH (g)	Chicken feathers (g)
SB1-45/TPS-EVOH/CF	45	12	3
SB1-50/TPS-EVOH/CF	50	8	2
SB1-55/TPS-EVOH/CF	55	4	1
SB2-45/TPS-EVOH/CF	45	12	3
SB2-50/TPS-EVOH/CF	50	8	2
SB2-55/TPS-EVOH/CF	55	4	1
SB3-45/TPS-EVOH/CF	45	12	3
SB3-50/TPS-EVOH/CF	50	8	2
SB3-55/TPS-EVOH/CF	55	4	1

SB1-elastomer with 45% styrene content, SB2-elastomer with 32% styrene content, SB3-elastomer with 25% styrene content, TPS-EVOH with 75% TPS content.

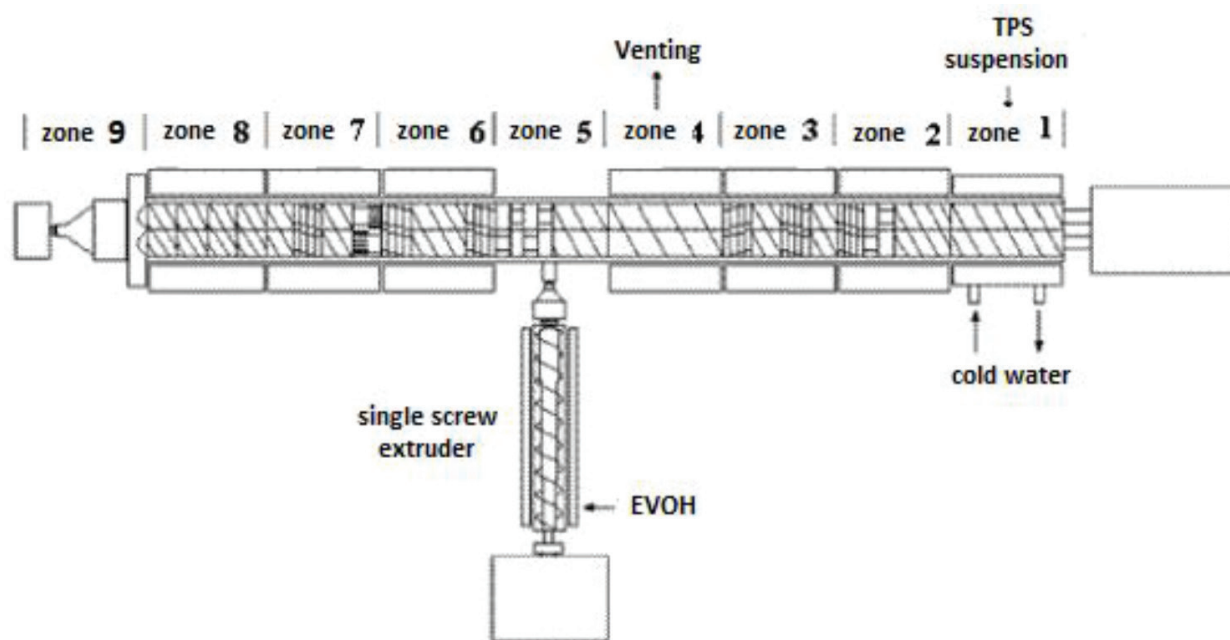
**Table 1.** Identification codes for prepared composites.

to take advantage of its properties to obtain materials with a higher performance than conventional ones. In this work, three SB elastomers with different styrene contents were combined with a TPS-EVOH blend, and additional to that, CF was added to obtain a composite that presents enhanced properties. The effect of styrene content in SB elastomer was studied. **Table 1** shows the identification codes for prepared composites. By means of infrared spectroscopy (FTIR), the possible chemical reactions between components in composite were evaluated, and thermal properties were evaluated by means differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA), and thermogravimetric analysis (TGA).

## 2. Experimental

### 2.1. Materials

Chicken feather (CF) was obtained from a local slaughterhouse in Altamira city, México, and three types of styrene-butadiene (SB) used were SB1 45% styrene content, SB2 32% styrene content, and SB3 25% styrene content, provided by Dynasol Elastomers S.A. de C.V. Chicken feathers (CFs) were cleaned with several washes, first with distilled water and then with acetone and finally with ethanol; after that CFs were dried at room temperature to be clean, sanitized, and odor free, and then proceeded to remove the barbules from quill, that was cut it into small pieces [1, 25]. A twin screw extruder ZSK30 with nine heating zones was used to obtain the mixtures of TPS-EVOH. The EVOH melted at 200°C was fed in zone 5 using the single-screw extruder Killion KTS-100 at full speed. The mixing of EVOH with TPS started from zone 5 to zone 8. In the pumping zone 9, the pressure of the extrudate was increased. The screw speed for all blends was 150 rpm. Mixtures were prepared with 75% TPS proportion [36]. **Figure 3** shows the configuration of double screw extruder to obtain the blends with EVOH.



**Figure 3.** Configuration of double screw extruder with nine heating zones, to obtain TPS-EVOH mixtures using a single screw extruder to melt at 200°C the EVOH.

## 2.2. Preparation elastomer/TPS-EVOH/keratin composite

The elastomer/TPS-EVOH/keratin composites were prepared by melting the mix using a plasticorder/Brabender PL2000 torque rheometer, establishing the optimum conditions at 185°C with 20 min of mixing, using roller blades at 100 rpm speed. Then, the materials were compressed in a Dake press with 10 tons during 20 min, using appropriate molds. **Table 1** shows the codes used for identification of composites.

## 2.3. Composites characterization

### 2.3.1. Infrared spectroscopy (FTIR)

The infrared spectroscopy technique was used to identify functional groups of materials, and for that purpose, equipment Perkin Elmer Spectrum One model was used, with attenuated total reflectance (ATR) technique with ZnSe plates in a range of 4000–600  $\text{cm}^{-1}$  with 12 scans.

### 2.3.2. Differential scanning calorimetry (DSC)

The differential scanning calorimetry (DSC) was used to determine the thermal transitions of the composites, using Perkin Elmer DSC8000 equipment. The employed method first consists of heating cycle from 30 to 200°C at 10°C/min, then a cooling cycle from 200°C up to -100°C, and the sample was kept for 5 min at this temperature and a second heating ramp from -100 to 200°C was carried out, with heating rate of 10°C/min, taking the second heating for analysis. The sample amount used was  $10 \pm 2$  mg, in an inert atmosphere of nitrogen, with a flow rate of 20 mL/min.

### 2.3.3. Dynamic mechanical analysis (DMA)

The dynamic mechanical analysis was carried out in a DMA-Q800 TA-Instrument, with a double cantilever clamp, and sample dimensions were  $30 \times 12 \times 3$  mm in a rectangular shape (length, wide, thickness). Analysis were carried out in multifrequency mode with temperature range from  $-100$  to  $200^\circ\text{C}$ , with a heating rate  $5^\circ\text{C min}^{-1}$ , 1 Hz frequency, and amplitude  $2 \mu\text{m}$ .

### 2.3.4. Thermogravimetric analysis (TGA)

The thermogravimetric analysis was carried out in an SDT (DSC-TGA) Q600 TA Instrument equipment under an  $\text{N}_2$  atmosphere with  $100 \text{ mL/min}$  flow, in a temperature range from  $40$  to  $600^\circ\text{C}$  with  $10^\circ\text{C/min}$  rate, using  $10 \pm 2$  mg sample.

## 3. Results

### 3.1. Infrared spectroscopy of elastomer/TPS-EVOH/keratin composite

Figure 4 shows the IR spectra for SB3, TPS-EVOH, CF, and SB3/TPS-EVOH/CF composites from  $4000$  to  $600 \text{ cm}^{-1}$ . It is possible to identify some of the functional groups in the blends of the elastomers with TPS-EVOH and CF. The SB3 signals at  $3000$  and  $3100 \text{ cm}^{-1}$  are associated with unsaturated carbons; meanwhile, at  $2900$  and  $2850 \text{ cm}^{-1}$ , the signals are related to the

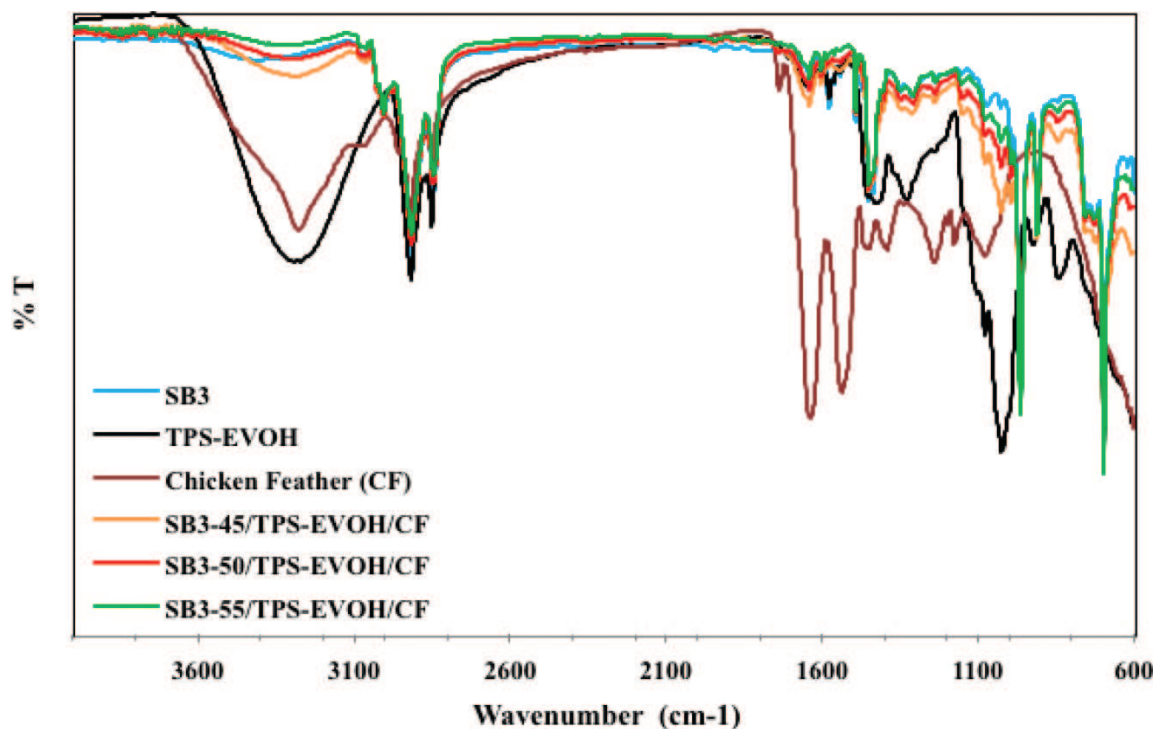


Figure 4. FTIR spectra of SB3, TPS-EVOH, CF, and SB3/TPS-EVOH/CF composite.



stretching of methyl and methylene groups; besides, the region of the aromatic ring is visible from 2000 to 1850  $\text{cm}^{-1}$  [35]. The CF signals at 3300  $\text{cm}^{-1}$  correspond to the ordered regions of NH group of amides A  $\alpha$ -helix conformation, at 2950  $\text{cm}^{-1}$  is related to the asymmetry vibration of CH group of methyl, and the band at 1710  $\text{cm}^{-1}$  is matched to the vibration of amides I of  $\beta$ -sheet conformation, for C=O group of amides I  $\alpha$ -helix at 1650  $\text{cm}^{-1}$  and at 700  $\text{cm}^{-1}$  attributed to the vibration of C–S group. The main groups assigned at 1650 and 1550  $\text{cm}^{-1}$  peaks from the chicken feather keratin are amide I and amide II bands, respectively. The peaks at 1500, 1450, and 1250  $\text{cm}^{-1}$  are attributed to a plane bending of NH group that corresponds to  $\beta$ -sheet conformation, the bending of  $-\text{CH}_3$  group, and CN group of amides III, respectively [37]. The glycerol absorption peaks are at 1109, 1042 and 994  $\text{cm}^{-1}$ . The signals at 3330  $\text{cm}^{-1}$  correspond to hydroxyl stretching of EVOH and are evident by the high amount of hydroxyl groups in the chemical structure [38]. The vibrations at 1150, 1100 and 1050  $\text{cm}^{-1}$  are assigned to vibrations of C–C group, a peak around 700  $\text{cm}^{-1}$  is attributed to vibration of C–S group, and finally, vibrations at 970, 910, 760, and 690  $\text{cm}^{-1}$  show the evidence of unsaturated aromatic carbon deformations [24, 39, 40]. Composites SB/TPS-EVOH/CF show typically the same signals, and the variations are attributed to elastomer content, and it is not possible to identify any evidence of a chemical reaction between materials.

### 3.2. Differential scanning calorimetry (DSC)

**Table 2** presents DSC results for elastomers, CF and for composites. It was observed that CF showed two transitions, one around 140°C and the second one around 260°C, attributed to the crystalline melting temperature of keratin, the main component of CF, corresponding with

Material	Transition (°C)		
Chicken feather (CF)		140	263
SB1	–40		
SB1-45/TPS-EVOH/CF	–82	58	162
SB1-50/TPS-EVOH/CF	–85	48	169
SB1-55/TPS-EVOH/CF	–92	6	175
SB2	–33		
SB2-45/TPS-EVOH/CF	–88	48	158
SB2-50/TPS-EVOH/CF	–89	39	164
SB2-55/TPS-EVOH/CF	–95	31	182
SB3	–63		
SB3-45/TPS-EVOH/CF	–83	131	165
SB3-50/TPS-EVOH/CF	–85	28	159
SB3-55/TPS-EVOH/CF	–90	–4	151

**Table 2.** Transition value for SB/TPS-EVOH/CF composites obtained by DSC.

previous reports [8]. Other reports indicate that CF did not show any melting peak [18], and also there are reports that around 300°C the disulfide bonds and denaturation of helix structure of keratin occurs [21]. Other reports [9] are known that T<sub>g</sub> value of keratin is affected by water concentration and the content of alpha and beta keratin. The SB elastomers only show a T<sub>g</sub> value which depends on the styrene content varying from -40°C for elastomer with higher styrene content, and -63°C for elastomer with lower styrene content. These results are according with soft and hard segments of copolymer [41]. The SB-TPS/EVOH/CF composites show two T<sub>g</sub> values, one at low temperatures (around -90°C), the second one depends on styrene content in elastomer, 48°C for higher styrene content in elastomer and 28°C for lower styrene content, which is indicative that there is an effect of hard segments of styrene in composite structure, due to the concentration of keratin was constant. Another interesting point is that lower T<sub>g</sub> value (attributed to butadiene segments in elastomer) also changed in SB/TPS-EVOH/CF composite moving at a temperature around -94 to -85°C, indicative that soft segments in composites are affected. These results indicate that the softness of materials is improved and the molecular level, produced by polypeptide chains of keratin with elastomer structure. A third transition was identified in SB/TPS-EVOH/CF composites around 160°C, which is not been reported before, however as was discussed before, can be attributed to keratin and the diminish is due the water content, in this case OH groups from TPS and EVOH which effects on keratin structure providing to material a soft characteristic.

Janowska et al. [9] reports that DSC technique cannot be a good option to evaluate T<sub>g</sub> due to their considerable thermal effect caused by evaporation of physically combined materials, in this case TPS and EVOH, which can mask the results due to a considerable effect of water content. Nevertheless, it can be possible to identify an effect of styrene content in an elastomer over T<sub>g</sub> of composites.

### 3.3. Dynamic mechanical analysis (DMA)

DMA is a useful technique to determine the viscoelastic properties of composite materials related to primary relaxations and other parameters. Dynamic mechanical properties are used for detection of damping peaks, elastic, and loss modulus changes with temperature [26]. Dynamic mechanical analysis (DMA) for TPS and blends is a useful tool to evaluate the phase separation relaxations and viscoelastic properties [42]. DMA can find a low-temperature peak around -40°C attributed to the secondary relaxation of starch and corresponds to the secondary transition of glycerol-rich domains, whereas a higher temperature peak is due to the primary transition of amylopectin-rich domain [42]. DMA was performed to evaluate the effect of elastomer type on an SB/TPS-EVOH/CF composite. **Figure 5** shows the storage modulus (E') versus temperature for SB1, TPS-EVOH, and SB1/TPS-EVOH/CF composites. The dynamic mechanical properties of TPS blends have been studied, TPS can form immiscible blends due to the high interfacial tension of polar and nonpolar segments of components. TPS-EVOH shows two relaxations around -40°C and 35°C, attributed to both components TPS and EVOH, which are partially miscible (see tan δ curve for TPS in **Figure 6**). High concentrations of plasticizer cause a heterogeneous system, resulting from glycerol and starch domains in compounds [43, 44]. According to results, for the composite SB1-45/TPS-EVOH/CF (**Figure 5**) the storage modulus has a good thermomechanical behavior compared to the compound with the highest content of SB (SB1-55/TPS-EVOH/CF), where the pure SB1 elastomer has a acceptable thermomechanical

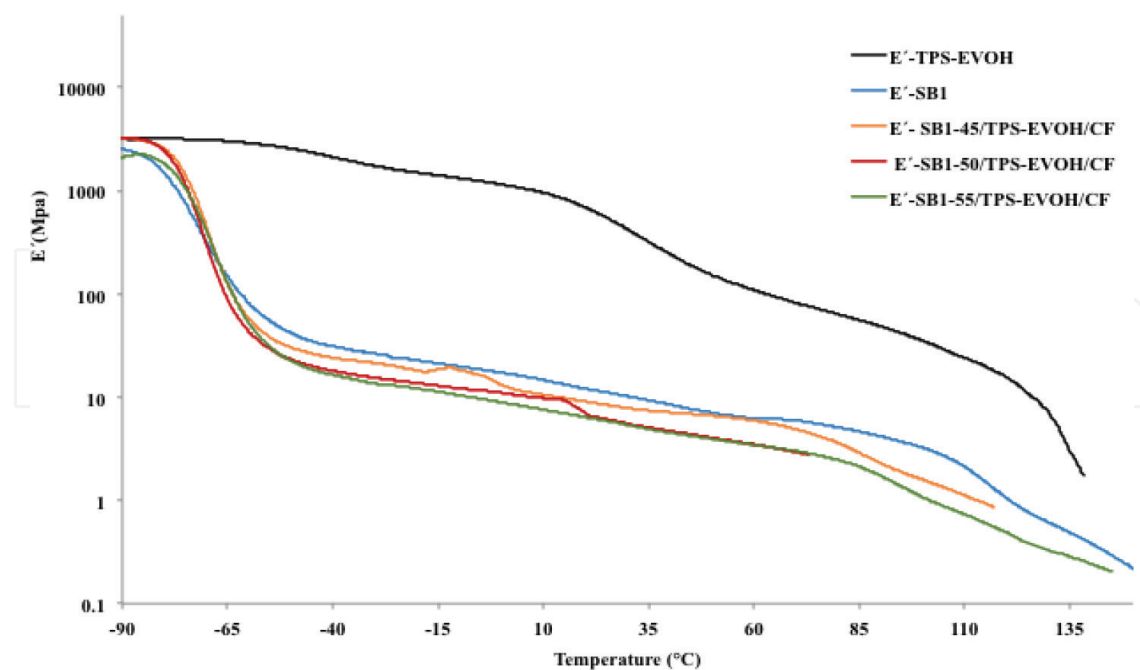


Figure 5. Storage modulus curve from DMA for SB1/TPS-EVOH/CF composites.

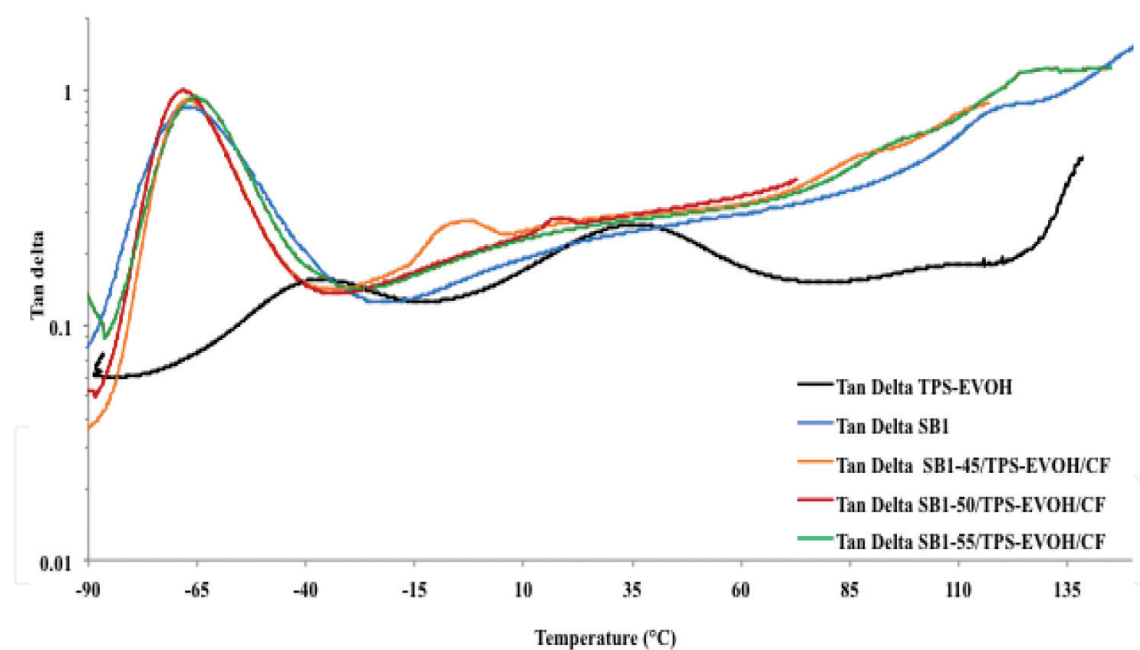


Figure 6. Tan  $\delta$  curve from DMA for SB1/TPS-EVOH/CF composites.

behavior, but even so below the blend TPS-EVOH. In general, the same behavior was observed in the composites prepared with SB2 and SB3 elastomers. The modulus of TPS composites is typically higher than synthetic thermoplastics, indicating that inclusion of elastomer to TPS-EVOH has no reinforcement in matrix, due to the complexity of structure of the obtained material. Previous works are contradictory about the increasing and diminishing of storage modulus value about the reinforcement when particles are added to a polymer matrix [25].

Comparing TPS-EVOH/CF composites with SB1, SB2, and SB3, the storage modulus decreases, which has lower styrene content in elastomer; this behavior can be attributed to a steric hindrance of hard segments of styrene present in elastomer (**Figure 4**). The behavior might be due to free movement in the polymer chain at high temperatures and have some agreement with the results of DSC analysis (see **Table 2**).

The keratin addition has a significant effect on SB/TPS-EVOH/CF composites, increasing the initial value of storage modulus with respect to pure SB copolymer, causing a significant reinforcement effect in the rubber plateau region [31, 42]. A good interaction of particle aggregates in a polymer matrix can reflect in decreasing storage modulus when they reach the plateau region, also indicating that composites have better high-temperature stability, as can be observed for composite with lower elastomer content in composite (In general, SB1, SB2, and SB3/TPS-EVOH/CF composites present the similar behavior.) The  $T_g$  values of composites using  $\tan \delta$  (**Figure 6**) signal are, however, not affected by the CF inclusion due to the aggregate size and limited surface area [45]. The  $\tan \delta$  (**Figure 6**) is an useful tool to identify the interaction existing between the polymeric matrix (including the TPS-EVOH) and the keratin as reinforcement, in which a strong bond is reflected in a low  $\tan \delta$  value, although in this case, it has been used as an elastomeric matrix, which have higher  $\tan \delta$  values. It is observed that  $T_g$  value in the SB/TPS-EVOH/CF compounds is affected significantly with the CF addition and with the TPS-EVOH presence, and this is could be related to the result from  $\tan \delta$  curve. Nevertheless, the SB1/TPS-EVOH/CF composite, at  $-94^\circ\text{C}$ , has the higher  $T_g$  value compared to the SB2/TPS-EVOH/CF and SB3/TPS-EVOH/CF composites. This same behavior has been reported before, in reference to no significant changes in  $T_g$  values by the effect of addition of CF as a reinforcement in the polymeric matrix [24, 32]. Jong [45] reports that for elastomer-protein composites, in the rubber plateau region, there is a very significant increase in the equilibrium storage modulus of composites of elastomers reinforced with proteins, and a better recovery behavior after eight cycles of dynamic strain, which indicates a stronger filler-rubber interaction. It was also found that the presence of aggregates causes an improvement in the effect of filler interaction with the matrix.

### 3.4. Thermogravimetric analysis (TGA)

The thermogravimetric analysis is used to predict the thermal stability of materials. When a reinforcement is added to a polymer matrix, it is necessary to identify the filler effect. For TPS, it has been reported that present thermal degradation due to loss of water below  $140^\circ\text{C}$ , around  $200^\circ\text{C}$  attributed to evaporation of water and glycerol and around  $330^\circ\text{C}$  from carbonization of starch [26, 38]. In the other hand, keratin decomposition has been reported before, presenting three steps, first around  $210^\circ\text{C}$  due to the protein denaturation, second one around  $360^\circ\text{C}$  resulting in a total destruction of protein, and third around  $510^\circ\text{C}$  for complete protein decomposition [2]. This is indicative that keratin is resistant to the action of elevated temperature. Other reports [1] found that CF lost moisture around  $30$  and  $116^\circ\text{C}$ , and temperature between  $214$  and  $410^\circ\text{C}$  presents the main decomposition stage with approximately 65% loss weight associated with breaking off the disulfide bonds in keratin structure, and the denaturation of the beta-protein structure as well as C–C bond degradation in the polymer backbone. **Figure 7** shows the TGA thermogram

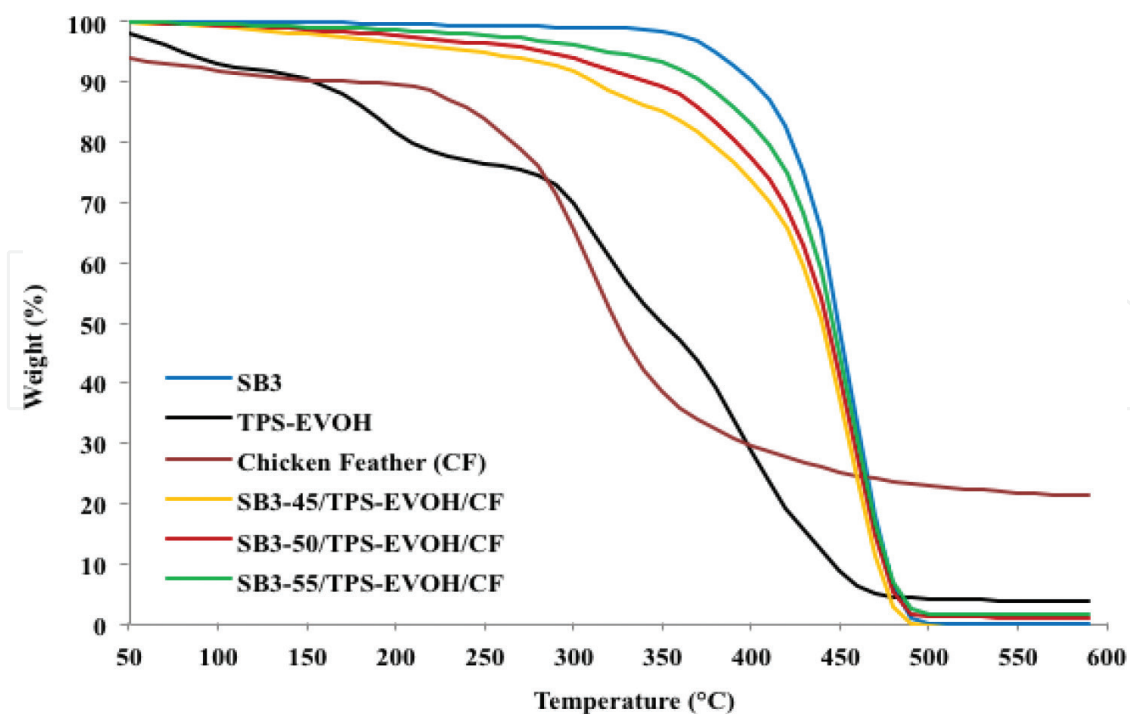


Figure 7. TGA thermograms for SB3, TPS-EVOH, CF, and SB3/TPS-EVOH/CF composite.

Material	Loss weight (%) at temperature (°C)						
	200	250	300	350	400	450	500
Chicken feather	89.7	83.8	65.3	38.6	29.7	25.3	23.0
TPS-EVOH	81.5	76.3	69.6	49.8	28.4	8.7	3.9
SB1	99.5	99.2	98.9	97.9	87.5	36.4	0.7
SB1-45/TPS-EVOH/CF	97.3	95.6	92.6	86.0	74.8	33.5	2.7
SB1-50/TPS-EVOH/CF	97.8	96.7	94.7	90.3	78.9	33.8	0.1
SB1-55/TPS-EVOH/CF	98.5	97.7	96.4	93.5	82.5	34.8	0.7
SB2	99.4	99.0	98.7	97.7	90.0	50.0	4.6
SB2-45/TPS-EVOH/CF	97.4	96.0	93.1	87.0	77.5	43.3	4.1
SB2-50/TPS-EVOH/CF	97.3	95.8	93.7	89.6	81.2	45.2	1.5
SB2-55/TPS-EVOH/CF	98.9	98.0	96.6	94.2	85.5	46.7	0.8
SB3	99.7	99.4	99.2	98.5	90.2	49.0	0.1
SB3-45/TPS-EVOH/CF	96.6	94.8	91.6	85.0	73.5	37.6	0.9
SB3-50/TPS-EVOH/CF	97.7	96.4	94.0	89.3	77.4	41.6	1.2
SB3-55/TPS-EVOH/CF	98.7	97.8	96.1	93.2	82.9	45.0	1.7

Table 3. Thermal data of loss weight for SB/TPS-EVOH/CF composites at different temperatures.

for SB3, CF, TPS-EVOH, and SB3/TPS-EVOH/CF composites with different SB3 contents. It can be observed that TPS-EVOH has three degradation steps, at around 130, 250, and 350°C, which are similar to reports of TPS thermal degradation [38]. CF has a similar behavior reported before as was discussed previously [1, 2]. Composite SB3/TPS-EVOH/CF has a similar behavior to that of SB3, so inclusion of elastomer improves the thermal degradation of TPS/EVOH/CF, due to the elastomer that has higher decomposition temperatures. A combinatorial effect of elastomer and CF can be present in the composites, as some reports found that keratin miscibility with polymer matrices increases the decomposition temperature in composites [25], in this work the content of CF was kept constant and the effect could be evaluated individually in thermal decomposition.

The composites with SB1 and SB2 have similar behavior compared with SB3 elastomer. **Table 3** shows the thermal data for SB/TPS-EVOH/CF composites at different temperatures with the aim to analyze. SB1/TPS0EVOH6CF composites present a lower loss weight when elastomer increases in formulation, which make sense, especially in region of 350–450°C, which is the main elastomer decomposition range. Composites prepared with the SB2 and SB3 elastomer has a better thermal resistance and better stability at higher temperatures, due to a lower loss weight, mainly at higher temperatures, and composites with SB3 elastomer showed a slight decrease in loss weight compared to composites with SB2 elastomer, which have the better thermal stability according to the results. Thermoplastic elastomer (TPE) is known due its higher thermal stability.

## 4. Conclusions

The infrared spectroscopy was not conclusive but indicates that there is no chemical interaction among components of composite. According with the styrene content present in the blend, it is possible to observed a better interaction among soft segments of the SB elastomers with the composites TPS-EVOH/CF. DMA results showed that the inclusion of SB elastomers in TPS-EVOH/CF do not have a positive effect, due to the decreased storage modulus compared to TPS-EVOH and pure SB, but the composites with lower SB content have a better behavior at lower and higher temperatures compared to the rest of the composites. The composites prepared with CF have been reported before that generates a similar behavior, but in this case, there was a synergistic effect, due to the structure of the composite material, so it can be attributed to SB elastomer of CF particles. The thermal behavior of the composites is very similar to that of the elastomer, which provides higher thermal stability as the styrene content increases therein.

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## References

- [1] Jimenez-Cervantes Amieva E, Velasco-Santos C, Martínez-Hernández AL, Rivera-Armenta JL, Mendoza-Martínez AM, Castaño VM. Composites from chicken feathers quill and recycled polypropylene. *Journal of Composite Materials*. 2015;**49**(3):275-283. DOI: 10.1177/0021998313518359
- [2] Prochon M, Janowska G, Przepiorkowska A, Kucharska-Jastrzabek A. Thermal properties and combustibility of elastomer-protein composites. *Journal of Thermal Analysis and Calorimetry*. 2012;**109**:1563-1570. DOI: 10.1007/s10973-011-2028-1
- [3] Martinez-Hernandez AL, Velasco-Santos C, De Icaza M, Castano VM. Microstructural characterisation of keratin fibres from chicken feathers. *International Journal of Environment and Pollution*. 2005;**23**(2):162-178. DOI: 10.1504/IJEP.2005.006858
- [4] Tran CD, Prosenc F, Franko M, Benzi G. Synthesis, structure and antimicrobial property of green composites from cellulose, wool, hair and chicken feather. *Carbohydrate Polymers*. 2016;**151**:1269-1276. DOI: 10.1016/j.carbpol.2016.06.021
- [5] Senoz E, Wool RP, McChalicher CW, Hong CK. Physical and chemical changes in feather keratin during pyrolysis. *Polymer Degradation and Stability*. 2012;**97**(3):297-307. DOI: 10.1016/j.polymdegradstab.2011.12.018
- [6] Brebu M, Spiridon I. Thermal degradation of keratin waste. *Journal of Analytical and Applied Pyrolysis*. 2011;**91**(2):288-295. DOI: 10.1016/j.jaap.2011.03.003
- [7] Hill P, Brantley H, Van Dyke M. Some properties of keratin biomaterials: Kerateines. *Biomaterials*. 2010;**31**(4):585-593. DOI: 10.1016/j.biomaterials.2009.09.076
- [8] Winandy JE, Muehl JH, Micales JA, Raina A, Schmidt W. Potential of chicken feather fibre in wood MDF composites. *Proceedings of EcoComp*. 2003;**20**:1-6
- [9] Janowska G, Kucharska-Jastrzabek A, Prochon M, Przepiorkowska A. Thermal properties and combustibility of elastomer-protein composites. Part II. Composites NBR-keratin. *Journal of Thermal Analysis and Calorimetry*. 2013;**113**:933-938. DOI: 10.1007/s10973-012-2796-2

- [10] Martínez-Hernández AL, Velasco-Santos C, de-Icaza M, Castaño VM. Dynamical-mechanical and thermal analysis of polymeric composites reinforced with keratin biofibers from chicken feathers. *Composites: Part B*. 2007;**38**:405-410. DOI: 10.1016/j.compositesb.2006.06.013
- [11] Yin XC, Li FY, He YF, Wang Y, Wang RM. Study on effective extraction of chicken feather keratins and their films for controlling drug release. *Biomaterials Science*. 2013;**1**:528-536. DOI: 10.1039/C3BM00158J
- [12] Saravanan S, Sameera DK, Moorthi A, Selvamurugan N. Chitosan scaffolds containing chicken feather keratin nanoparticles for bone tissue engineering. *International Journal of Biological Macromolecules*. 2013;**62**:481-486. DOI: 10.1016/j.ijbiomac.2013.09.034
- [13] Kreskin Z, Urkmez AS, Hames EE. Novel keratin modified bacterial cellulose nanocomposite production and characterization for skin tissue engineering. *Materials Science and Engineering C*. 2017;**75**:1144-1153. DOI: 10.1016/j.msec.2017.03.035
- [14] Simmons S, Thomas EL. The use of transmission electron microscopy to study the blend morphology of starch/poly (ethylene-co-vinyl alcohol) thermoplastics. *Polymer*. 1998;**39**:5587-5599. DOI: 10.1016/S0032-3861(98)00025-1
- [15] Rosa MF, Chiou B, Medeiros ES, Wood TG, Mattoso LHC, Orts WJ, Imam SH. Biodegradable composites based on starch/EVOH/glycerol blends and coconut fibers. *Journal of Applied Polymer Science*. 2008;**111**:612-618. DOI: 10.1002/app.29062
- [16] Rosa MF, Chiou B, Medeiros ES, Wood DF, Williams TG, Mattoso LHC, Orts WJ, Imam SH. Effect of fiber treatments on tensile and thermal properties of starch/ethylene vinyl alcohol copolymers/coir biocomposites. *Bioresource Technology*. 2009;**100**:5196-5202. DOI: 10.1016/j.biortech.2009.03.085
- [17] Vaz CM, Reis RL, Cunha AM. Use of coupling agents to enhance the interfacial interactions in starch-EVOH/hydroxyapatite. *Biomaterials*. 2002;**23**:629-635. DOI: 10.1016/S0142-9612(01)00150-8
- [18] Leonor IB, Ito A, Onuma K, Kanzaki N, Reis RL. In vitro bioactivity of starch thermoplastic/hydroxyapatite composite biomaterials: An in situ study using atomic force microscopy. *Biomaterials*. 2003;**24**:579-585. DOI: 10.1016/S0142-9612(02)00371-X
- [19] Reis RL, Cunha AM, Allan PS, Bevis MJ. Structure development and control of injection-molded hydroxyapatite-reinforced starch/EVOH composites. *Advances in Polymer Technology*; **16**:263-277
- [20] Sinha Ray S. Polymer/layered silicate nanocomposite: A review from preparation to processing. *Progress in Polymer Science*. 2003;**28**:1539-1641. DOI: 10/1016/j.progpolymsci.2003.08.002
- [21] Flores-Hernández CG, Colín-Cruz A, Velasco-Santos C, Castaño VM, Rivera-Armenta JL, Almendarez-Camarillo A, García-Casillas PE, Martínez-Hernández AL. All green composites from fully renewable biopolymers: Chitosan-starch reinforced with keratin from feathers. *Polymer*. 2014;**6**:686-705. DOI: 10.3390/polym6030686



- [22] Barone JR. Polyethylene reinforced with keratin fibers obtained from chicken feathers. *Composites Science and Technology*. 2005;**65**:683-692. DOI: 10.1016/j.compscitech.2004.09.030
- [23] Cheng S, Lau KT, Liu T, Zhao Y, Lam PM, Yin Y. Mechanical and thermal properties of chicken feather fiber/PLA green composites. *Composites Part B: Engineering*. 2009; **40**(7):650-654. DOI: 10.1016/j.compositesb.2009.04.011
- [24] Barone JR, Schmidt WF. Polyethylene reinforced with keratin fibers obtained from chicken feathers. *Composites Science and Technology*. 2005;**65**:173-181. DOI: 10.1016/j.compscitech.2004.06.011
- [25] Villarreal-Lucio DS, Rivera-Armenta JL, Rivas-Orta V, Díaz-Zavala NP, Páramo-García U, Gallardo-Rivas NV, Chávez-Cinco MY. Manufacturing composites from chicken feathers and polyvinyl chloride (PVC). In: Thakur VK, Thakur MK, Kessler MR, editors. *Handbook of Composites from Renewable Materials: Design and Manufacturing*. 2nd ed. Beverly: Wiley-Scrivener Publishing; 2017. pp. 159-174
- [26] Shanks R, Kong I. Thermoplastic starch. In: El-Sonbati A, editor. *Thermoplastic Elastomers*. InTechOpen; 2012. pp. 95-116. DOI: 10.5772/36295
- [27] Méndez-Hernández ML. Doctorate Thesis "Accelerated Aging Study of HDPE-Thermoplastic Starch Blends", Degree in Polymer Technology, Research Center in Applied Chemistry. Saltillo, Coahuila Mexico: CIQA; 2010
- [28] Wang C, Guo Z, Fu S, Wu W, Zhu D. Polymers containing fullerene or carbon nanotube structures. *Progress in Polymer Science*. 2004;**29**:1079-1141. DOI: 10.1016/j.progpolymsci.2004.08.001
- [29] Paul DR, Robeson LM. Polymer nanotechnology: Nanocomposites. *Polymer*. 2008;**49**: 3187-3204. DOI: 10.1016/j.polymer.2008.04.017
- [30] Wrzesniewska-Tosik K, Adamec J. Biocomposites with a content of keratin from chicken feathers. *Fibers & textiles in Eastern Europe*. 2007;**15**:106-112
- [31] Zha W, Han CD, Moon HC, Han SH, Lee DH, Kim JK. Exfoliation of organoclay nanocomposites based on polystyrene-block-polyisoprene-block-poly (2-vinylpyridine) copolymer: Solution blending versus melt blending. *Polymer*. 2010;**51**(4):936-952. DOI: 10.1016/j.polymer.2009.12.030
- [32] Spitalskya Z. Carbon nanotube-polymer composites: Chemistry, processing, mechanical and electrical properties. *Progress in Polymer Science*. 2010;**35**(3):357-401. DOI: 10.1016/j.progpolymsci.2009.09.003
- [33] Kviklys A, Lukosiute I. Kinetics and peculiarities of polyamide coatings formation from solutions. *Materials Science (Medziagotyra)*. 2004;**10**:177-181
- [34] Hernández-Martínez T, Salazar-Cruz BA, Rivera-Armenta JL, Chávez-Cinco MY, Méndez-Hernández ML, Páramo-García U. Evaluation of addition of reactive resin for an adhesive formulation of pressure-sensitive adhesive. In: Rudawska A, editor. *Adhesives. Applications and Properties*. InTechOpen; 2016. pp. 201-218. DOI: 10.5772/62603

- [35] Salazar-Cruz BA, Rivera-Armenta JL, García-Alamilla R, Mendoza-Martínez AM, de la Garza AE, Espiricueto SM. Evaluación térmica del curado de adhesivos base SBR usando peróxido de dicumilo. *Quimica Nova*. 2015;**38**:651-656. DOI: 10.5935/0100-4042.20150067
- [36] Méndez-Hernández ML, Tena-Salcido CS, Zandoval-Arellano Z, González-Cantú MC, Mondragón M, Rodríguez-González FJ. The effect of thermoplastic starch on the properties of HDPE/TPS blends during UV-accelerated aging. *Polymer Bulletin*. 2011;**67**:903-914. DOI: 10.1007/s00289-011-0501-4
- [37] Rivera-Armenta JL, Flores-Hernández CG, Del Angel-Aldana RZ, Mendoza-Martínez AM, Velasco-Santos C, Martínez-Hernández AL. Evaluation of graft copolymerization of acrylic monomers onto natural polymers by means infrared spectroscopy. In: Theophanides T, editor. *Infrared Spectroscopy: Materials Science, Engineering and Technology*. InTechOpen; 2012. pp. 245-260. DOI: 10.5772/2055
- [38] Mahdieh Z, Bagheri R, Eslami M, Amiri M, Shokrgozar MA, Mehrjoo M. Thermoplastic starch/ethylene vinyl alcohol/forsterite nanocomposites as a candidate material for bone tissue engineering. *Materials Science and Engineering C*. 2016;**C69**:301-310. DOI: 10.1016/j.msec.2016.06.43
- [39] Ma B, Qiao X, Hou X, Yang Y. Pure keratin membrane and fibers from chicken feather. *International Journal of Biological Macromolecules*. 2016;**89**:614-621. DOI: 10.1016/j.ijbiomac.2016.04.039
- [40] Khosa MA, Wu J, Ullah A. Chemical modification, characterization, and application of chicken feathers as novel biosorbents. *RSC Advances*. 2013;**3**(43):20800-20810. DOI: 10.1039/C3RA43787F
- [41] Reddy N, Hu C, Yan K, Yang Y. Thermoplastic films from cyanoethylated chicken feathers. *Materials Science and Engineering: C*. 2011;**31**(8):1706-1710. DOI: 10.1016/j.msec.2011.07.022
- [42] Morton M, McGrath JE, Juliano PC. Structure-property relationships for styrene-diene thermoplastic elastomers. *Journal of Polymer Science, Polymer Symposia*. 1969;**26**:99-115. DOI: 10.1002/polc.5070260107
- [43] Taguet A, Huneault MA, Favis BD. Interface/morphology relationships in polymer blends with thermoplastic starch. *Polymer*. 2009;**50**:5733-5743. DOI: 10.1016/j.polymer.2009.09.055
- [44] Jiang W, Qiao X, Sun K. Mechanical and thermal properties of thermoplastic acetylated starch/poly(ethylene-co-vinyl alcohol) blends. *Carbohydrate Polymers*. 2006;**65**:139-143. DOI: 10.1016/j.carbpol.2005.12.038
- [45] Jong L. Effect of soy protein concentrate in elastomer composites. *Composites: Part A*. 2006;**37**:438-446. DOI: 10.1016/j.compositesa.2005.05.042

