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Study mechanical, swelling and dielectric properties of prehydrolysed banana fiber – Waste polyurethane foam composites

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Untreated and treated banana fiber by maleic anhydride together with waste polyurethane foam were used to produce composites. Treated banana fiber reduces swelling and improve strength and dielectric properties.

Also, addition of aluminum silicate exhibited enhancements in its dielectric properties at constant concentration lower than 10%. While, abrupt increase can be seen in the dielectric constant (ε') and dielectric loss (ε'') for samples contain more than 7.5% aluminum silicate. I.R and scanning electron microscope were studied.

1. Introduction

Polymeric composite insulators are being used increasingly in vehicle distributors and transmission electric system. Wood polymer composite are generally known as electrical insulators, they are able to withstand a potential difference between different points of a given specimen of material with the passage of small electric current and a low dissipation energy (Baiardo, Frisoni, Scandola, & Licciardello, 2002; Nabi Saheb & Jog, 1999). Due to increase demand of wood ultimately results in the erosion of environment, many efforts have been directed to the employment of natural cellulose.

Banana fiber is a lignocellulosic material, relatively inexpensive and abundantly available was assessed in terms of its fiber–matrix adhesion. Banana fiber is considered as an effective reinforcing constituent due to its good compatibility and bonding with resin matrix (Goda, El-Zawawy, & El-Khateeb, 2004). The hydroxyl-rich nature of natural lignocellulosic suggests they are particularly useful in thermosetting system such as polyurethane. Polyurethane contain two or more isocyanate groups per molecule, so, it has the ability to produce crosslink-free hydroxyl groups with cellulose leading to more internal bonds and consequently, high compression strength.

$$\underset{\text{isocyanate(functional group of polyurethane)}}{R-N{=}C{=}O} + \underset{R'\ \text{of(cellulose fiber)}}{R'-OH} \rightarrow R-NH-COOR'$$

Polyurethane serves as crosslinking agent and as a good electrical insulation (Goda, 2004; Rials, Wolcott, and Nassar, 2001). Addition of fillers such as carbon black or silica increased the electrical insulation of the composite but breakdown strength (Rials et al., 2001; Ruy Alberto, Cacilda, Salvador, Luizc, & Gilberto, 2003). In this work, prehydrolysed banana fiber treated or untreated with maleic anhydride together with different concentrations of waste polyurethane were used to produce composite. The strength properties, water absorption, polymer concentration, pressure as well as dielectric properties were studied. Also, infra red and scanning electron microscope were examined.

2. Experimental

2.1. Materials

Banana fibers, waste polyurethane foam, maleic anhydride and aluminum silicate.

2.2. Treatment of banana fiber

Prehydrolyzed banana pulp was prepared from banana pseudostem using XPress cooker with water, water to fiber ratio was 5:1, at 120 °C and time for hydrolysis was 2 h. This leads to reduce the content of non-cellulosic compounds that cement the fiber aggregates. So, the fibers became liberated from the bundles as individual entities and therefore their efficiency as composite reinforcements is increased (Goda et al., 2004). The fibers were

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esterified by using 2% maleic anhydride in xylene. The fibers stirred properly in maleic anhydride solution for 20 min, then left for 18 h. at room temperature. The fibers were filtered and dried in an oven at 60 °C till constant weight (Naik & Mishra, 2004).

2.3. Preparation of the composite

A specific amount of ground sample was then impregnated in polymer solution. After that the mixture should be stirred properly and kept at room temperature for 24 h. The homogeneous mixture was then processed as follows: 50 g dry sample were placed in a disc form, diameter 15 cm, heated to 150 °C, and then pressed under 25 and 50 KN disc for 5 min.

2.4. Measurements

The composite samples were subjected to the following measurements.

2.4.1. Water absorption

A specific weight and thickness of such composites were immersed in boiling water for 2 h and in water for 24 h and 7 days at room temperature. After that, thickness and weights of the composites were measured again. Water absorption percent can be calculated as follows:

$$\text{Water absorption } \% = \frac{W_w - W_i}{W_t} \times 100$$

where W_i and W_w are the initial and wet weights of the composites, respectively. This test was measured according to the method of D 570–81 ASTM (American Society for testing, 1990).

2.4.2. Bending strength

Bending strength is defined as the maximum load should be applied to the sample to be broken and can be calculated by the following relation:

$$\text{Bending strength} = \frac{3pL}{2bd^2}\,\text{N/mm}^2$$

where p is the maximum bending load, L is the length of span, b is the width of specimen and d is the thickness of specimen. LLoyD Instrument LTD was used to measure bending strength.

2.4.3. Infrared spectra

The infrared spectra for treated and untreated banana fiber measured by using apparatus Jocco FTIR spectrophotometer, Japan. The samples were measured as KBr discs.

2.4.4. Scanning electron microscopy

Scanning electron microscopy (SEM) of fractured surfaces of composite test specimens were conducted on JEDL JEM-100 S electron microscope using the gold – Sputtering technique.

2.4.5. Dielectric measurements

The instrument used to measure the dielectric properties is HIOKI 3532-50 LCR HITESTER Japan. The test frequency can be set from 42 Hz to 5 MHz at high resolution. The electrical measurements were carried out through the prepared samples having 3.5 mm in thickness and 10 mm in diameter, in the frequency range of 100 Hz to 1 MHz at room temperature. The dielectric constant (ε') and dielectric loss (ε'') can be calculated as follows:

$$\varepsilon' = \frac{Cd}{\varepsilon_o A}$$

$$\varepsilon'' = \varepsilon_o \tan\delta$$

where C is the capacitance of the measured sample in Farad, d is the sample thickness in meter; A is the cross section area of sample. ε_o is the permittivity of vacuum = $8.85 * 10^{-12}$ Fm^{-1}. $\tan\delta$ is the loss tangent or the dissipation factor.

3. Result and discussion

3.1. Effect of treatment and polyurethane concentrations

It can be seen from Table 1 and Fig. 1 that the treated composite with maleic anhydride showed higher strength properties and lower water absorption comparing with that obtained for the untreated composite. Composites prepared from waste polyurethane foam and treated banana fiber by maleic anhydride have bending strength 4 N/mm^2 higher than that obtained for untreated composites. In addition, swelling of the treated composites showed decrease by 3–4% comparing with that obtained for the untreated composites. Aluminum silicate with different concentrations affects dielectric properties of the same composite. This results from that the maleic anhydride is used as a coupling agent contains functional groups which have capability to react with the fiber and polymer. In addition, hydrogen bonding has been formed that improve the fiber–matrix reaction. Consequently, developing of highly cross linked interface region between fiber and matrix increased the strength of the interfacial bonding between them (Kamel, Adel, El-Sakhawy, & Adeeb, 2008; Naik & Mishra, 2004). We can conclude that the treatment of composite by maleic anhydride reduced its swelling and improved its mechanical properties.

It is obviously clear from Table 1 and Fig. 1, for both untreated and treated composites, that increasing polymer concentrations improved the strength properties (bending strength and modulus elasticity) and decreased water absorption. The noticeable effect of

Table 1

Properties of composites prepared from banana fiber treated or untreated by maleic anhydride and waste polyurethane as adhesive material.

Composite	Polymer (%)	Strength properties		Water absorption					
		Bending strength (N/mm^2)	Modulus of elasticity (N/mm^2)	After immersion in boiling water		After immersion in water for 24 h		After immersion in water for 7 days	
				(W) %	(T) %	(W) %	(T) %	(W) %	(T) %
Untreated composite	10	7.9	1480.5	41.2	25	40	26.5	44	27.8
	20	8.8	2080	36	17.3	35	18	38	20
	30	11.6	2250.7	32	14	29.2	16	33	16
Treated composite	10	10.1	2050.3	40	23.2	36	20.6	40	25
	20	11.3	2640.2	35	14.1	32	14.3	36	15.3
	30	15.3	2830	25	11.5	22.9	11.5	30	11.5

Where W is expressed as a weight and T is a thickness Pressure = 50 KN.

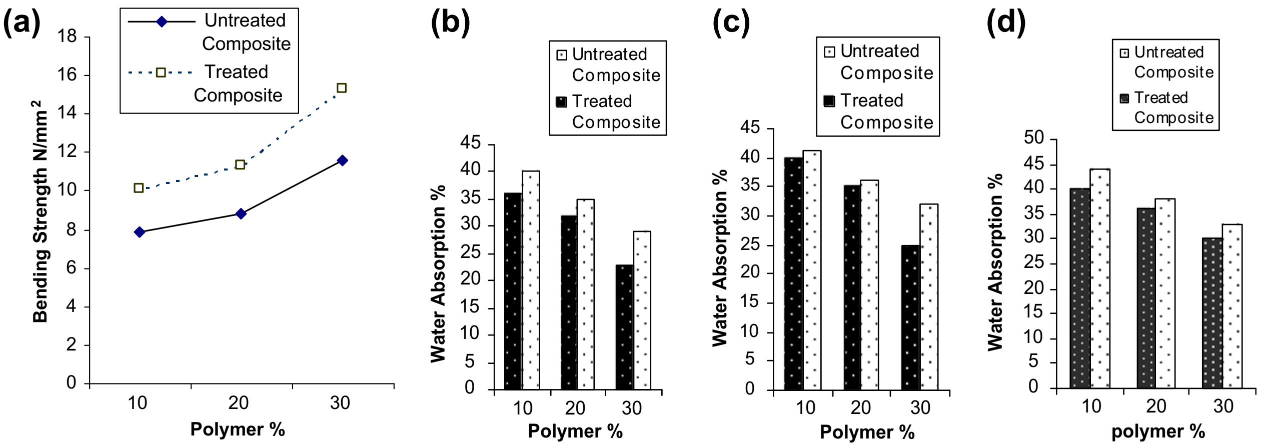

Fig. 1. (a) Effect of polyurethane concentrations on the bending strength of the treated and untreated composites, measured under pressure 50 KN. (b) Relationship between water absorption (weight after immersion in water for 7 days) and different polymer percent. (c) Relationship between water absorption (weight after immersion in water for 24 h) and different polymer percent. (d) Relationship between water absorption (weight after immersion in boiling water for 2 h) and different polymer percent.

polyurethane concentration on properties of the composites originates from that polymer has a thermoplastic property, which may serve as a binder to the banana fiber composite. So, by increasing polymer concentration, the binder becomes much stronger due to formation of additional hydrogen bonds and consequently increasing of the internal bond (Mansour, Abd El-hady, Kamel, & Goda, 2001). This leads to enhancements of mechanical properties of the composite. The decrease in water absorption percentage with increase polymer concentration originates from decreasing void content of the composite (Nassar, 2007; Mansour, Kamel, & Nassar, 1998).

3.2. Effect of compression on the treated composite containing 20% polyurethane

Table 2 and Fig. 2 show that the strength properties of the treated composite are increased more twice if the pressure increased from 25 to 50 KN in addition decreasing of water absorption by approximately 60%. Since, increasing the pressure makes the fibers or particles of composite combine strongly with polymer due to its formation of strong chemical bond between the reinforcement and matrix. This in turn leads to more compact composite with higher density i.e. higher internal bond and consequently higher strength properties with lower water absorption (Naik & Mishra, 2004).

3.3. Effect of aluminum silicate on the composite properties

Different concentrations (5%, 7.5% and 10%) of aluminum silicate was added to the treated banana fiber where it has a good insulation properties (Ruy Alberto et al., 2003) in presence of 20% polyurethane and then pressed under 50 KN, at 150 °C, for 5 min. Table 3 and Fig. 3 show that addition of aluminum silicate decreased the strength properties of the composites and increased water absorption. This could be attributed to that aluminum silicate interfere with the fiber bonds, forming weak fiber- filler bonds instead of strong fiber–fiber bonds and therefore a decrease in strength properties is expected (Ullmann's encyclopedia of industrial chemistry, 1991).

3.4. IR spectroscopy

As clear from Fig. 4(a and b), a wide band of spectra characterizing hydroxyl group of the anhydroglucose is detected between 3423 cm^{-1} and 3421 cm^{-1}. There is a band between the two spectra at 2922 cm^{-1} and 2857 cm^{-1} due to stretching vibration of –CH_3 and CH_2. The major difference between the spectra obtained for treated or untreated banana fiber was due to the presence of C=O peak at 1722 cm^{-1} in the treated banana fiber. Vibration stretching of C=O observed at 1722 cm^{-1} taking place when it interacts with maleic anhydride resulting in formation of bonded ester group (Bisanda, 1993; Hassan, Rowell, Fadel, Yaakoub, & Alfred, 2000).

3.5. Scanning electron microscope

Figs. 5(a and b) showed that the banana fiber–polyurethane composite, treated with a maleic anhydride presents certain adhesion between the fibers and matrix, and has more compact structure than untreated composite. Since the fibers are not set free, suggesting that they suffered a break during the impact test. It is known that cellulosic fibers have a cell arrangement which can divert the crack path by blunting it. Thus the crack does not have a straight path, because it has to move around the fiber cells and ultimately stop (Li & Matuana, 2003).

Table 2
Effect of pressure on the properties of the treated composite by maleic anhydride.

Composite	Pressure (kN)	Strength properties		Water absorption					
		Bending strength (N/mm^2)	Modulus of elasticity (N/mm^2)	After immersion in boiling water		After immersion in water for 24 h		After immersion in water for 7 days	
				(*W*) %	(*T*) %	(*W*) %	(*T*) %	(*W*) %	(*T*) %
Treated composite	0	0	0						
	25	4.9	805.7	105	57	96	52	125	70.6
	50	11.3	2640.2	35	14.1	32	14.2	38	15.3

Where W is expressed as a weight and T is a thickness, (polymer percent 20%).

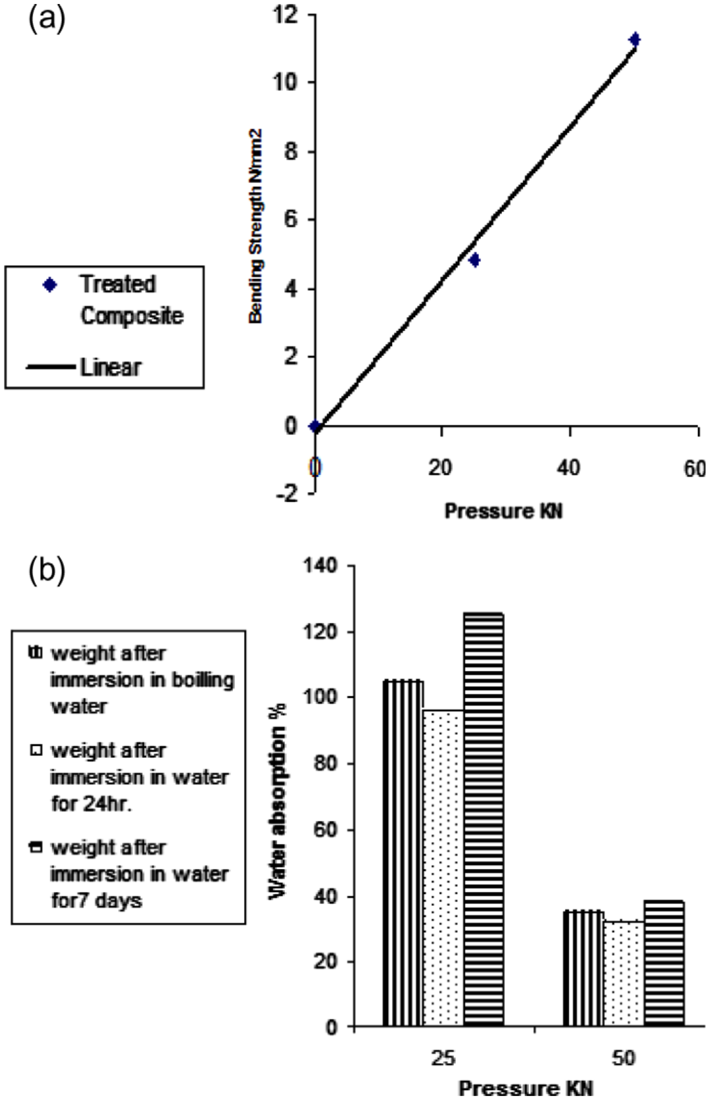

Fig. 2. Effect of pressure on the bending strength (a) and water absorption (b) of the treated composite containing 20% polyurethane.

Fig. 5(c) shows that there are minute cells formed throughout the composites after adding of aluminum silicate. These minute cells decrease to a large extent the free-OH group leading to decrease the dielectric properties of the composites (Inai, Sawa, Yoshinitsu, Ozaki, & Shiniz, 2004).

3.6. Dielectric studies

In an attempt to understand the effects of polyurethane (PU) treatment with maleic anhydride and aluminum silicate on the dielectric behavior of the composite based cellulose, two studies were undertaken. The first study was concerned with the effect of PU contents on the dielectric properties of the treated and untreated composite at 1 kHz while the second study was concerned with the effects of adding aluminum silicate (Al_2SiO_5) to the treated 20% PU sample on the dielectric properties, at a wide range of frequency.

For the first study, the dielectric constant (ε') and the dielectric loss (ε'') of the treated and untreated composites at 1 kHz, measured at room temperature and as a function of polyurethane con-

Table 3
Effect of aluminum silicate on the mechanical and water absorption properties of the treated composite.

Composite	Aluminum silicate	Strength properties		Water absorption					
		Bending strength (N/mm^2)	Modulus of elasticity (N/mm^2)	After immersion in boiling water		After immersion in water for 24 h		After immersion in water for 7 days	
				(*W*) %	(*T*) %	(*W*) %	(*T*) %	(*W*) %	(*T*) %
Treated Composite	–	11.3	2640.2	35	14.1	32	14.2	38	15.3
	5	11	2600.3	44	20.6	43	20.6	45	22
	7.5	10.6	2580	50	25	48.6	24.8	50.3	26.4
	10	10.2	2550.6	55.4	32.6	55	31.2	70.3	38

Where *W* is expressed as a weight and *T* is a thickness, (polymer percent 20%).

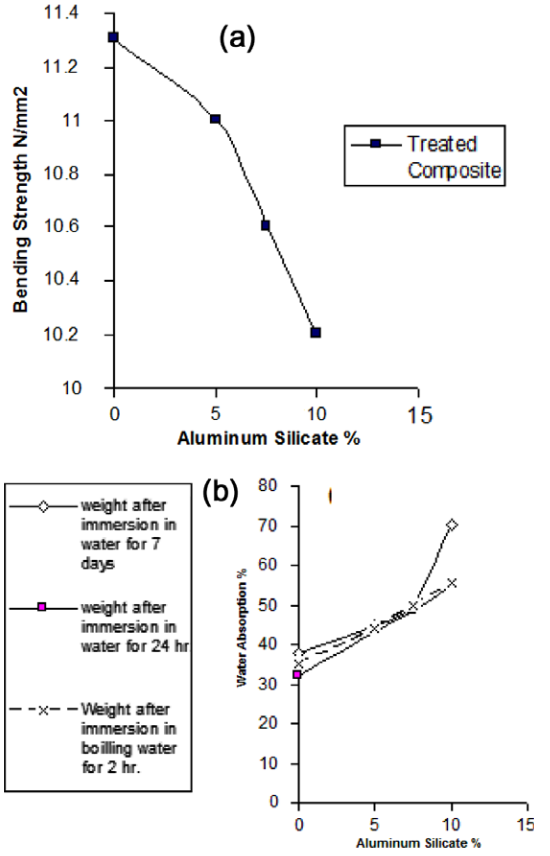

Fig. 3. Effect of aluminum silicate on bending strength (a) and water absorption (b) of the treated composites containing 20% polyurethane, measured under pressure 50 KN.

tents, were investigated, see Table 4. As seen from this table, both ε′ and ε″ for the treated and untreated composites showed continuous decrease by increasing PU contents. However, the dielectric properties of the treated composite have lower values comparing with those obtained for the untreated composite even at small concentrations of PU. The decrease in the dielectric properties of the treated composite may have some relations to that maleic anhydride affecting compatibility between banana fiber and polyurethane which may decrease the mobility of dipoles and/or charge carriers. The obtained low dielectric loss refers to enhancements of the dielectric properties (electrical insulation properties) for the composite treated with maleic anhydride.

In the second study, the effect of adding Al_2SiO_5 with different percentages (5%, 7.5% and 10%) on the dielectric properties of the treated 20% PU sample were investigated in the frequency range 42 Hz–1 MHz (Fig. 6). It is clear from this figure that both ε′ (a) and ε″ (b) decreases by increasing frequency and increases by increasing Al_2SiO_5 concentrations. At low frequencies and high concentrations, the rate of decreasing for both ε′ and ε″ is very high, while at higher frequencies the rate becomes very slow. The more realized interpretation for this behavior is that at low frequencies, the dipole moments and charge carriers (electrons, holes, ions, etc.), can freely move within the material under test and follow the varying of the electromagnetic field, while at higher frequencies, dipoles and charge carriers become unable to follow varying of the applied electric field resulting in a decrease of polarization.

From Fig. 6(a), it can also be found that ε′ increases with the increase of Al_2SiO_5 concentration, but at certain concentration (10%), its rate of increase abruptly changes and becomes higher. Such result could be attributed to the incorporation or interaction of aluminum silicate particles with the banana fiber treated with maleic anhydride. On the other hand, ε″ gradually increases with increasing Al_2SiO_5 contents and no abruptly changes can be detected.

The large values seen in ε′ could be attributed to separation of charges at the interfaces (Sillars, 1937; Wagner, 1914) which gives rise to an additional contribution to the polarization. Also, such large values can be seen in ε′, when charge carriers (electrons, ions, holes) blocked at the internal composite boundary layers (Max-

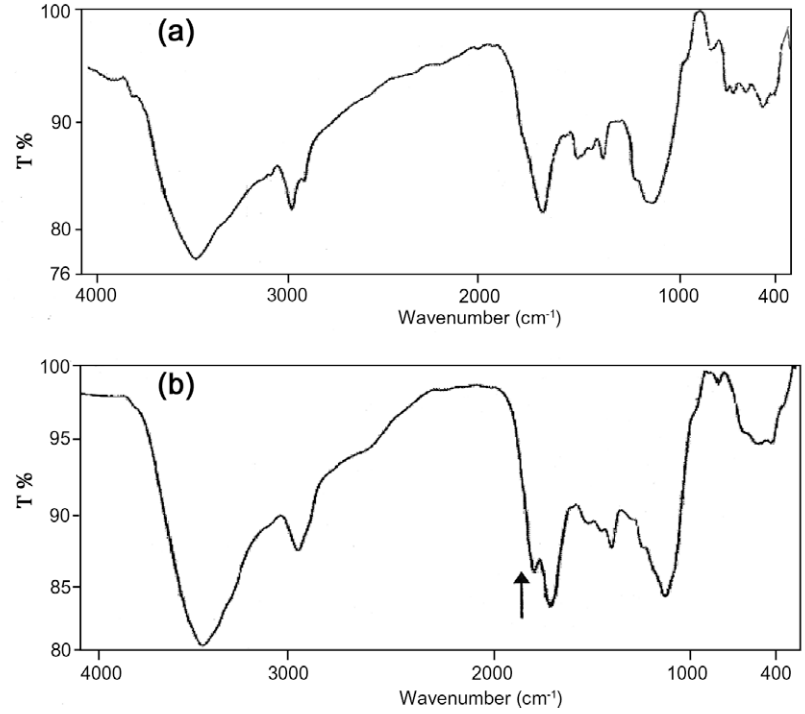

Fig. 4. IR spectra of untreated (a) and treated (b) composite from banana fiber with maleic anhydride.

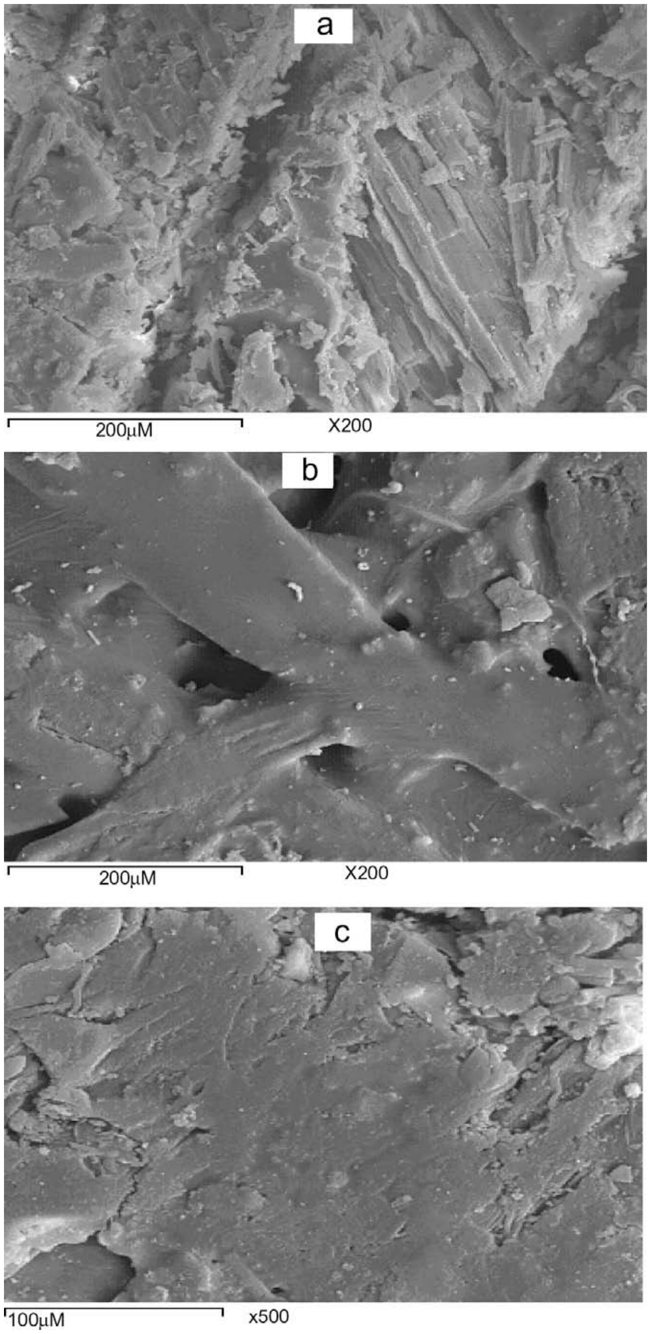

Fig. 5. SEM of the treated (a), untreated composite (b) and treated composite after adding aluminum silicate (c).

Table 4
The dielectric properties of the untreated and treated composites measured at 1 kHz as a function of polyurethane concentrations.

PU%	Untreated composite		Treated composite	
	ε'	ε''	ε'	ε''
10	137	26	115	19
20	143	22	130	15
30	157	16	134	13

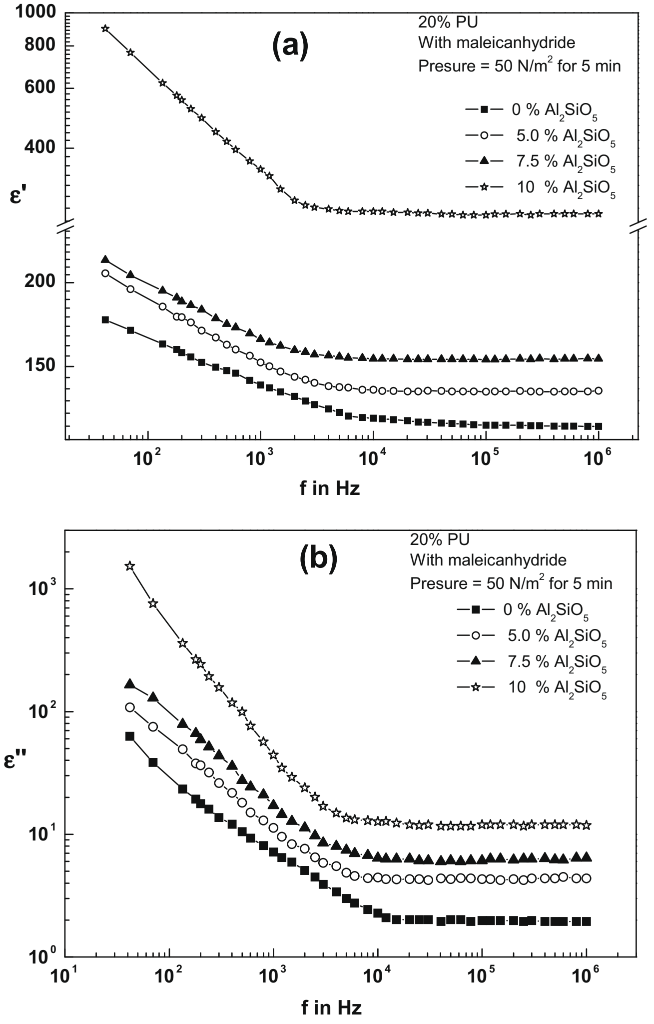

Fig. 6. The dielectric constant ε' (a) and dielectric loss ε'' (b) of the treated composite as a function of frequency (*f*) for sample with 20% polyurethane and loaded with different amount of aluminum silicate.

well/Wagner/Sillars – polarization) on a macroscopic scale and/or at the external electrodes contacting the sample (electrode polarization) on a macroscopic scale. Because the composite under study is considered as a heterogeneous system, then Maxwell/Wagner/Sillars effect seems to be more reasonable for the high values seen in ε'. On the other hand, the large values seen in ε'' at low frequencies could be attributed to the loss originated from DC conductivity. Quantity of DC conductivity results from migration of movable charges which forms a dielectric moment inside and on the surface of the material and also movements of bound charges which exist in the form of molecular electrical dipoles.

4. Conclusion

1. For the mechanical measurements, it was found that treatment of the banana fiber by maleic anhydride in addition of increasing polyurethane concentrations and applied high pressure, results in producing composite with higher strength properties and lower swelling.
2. For the IR spectroscopy measurements, the treated composite showed a band characterizing C=O of ester group at 1722 cm^{-1}.
3. For scanning electron microscope measurements, morphology of the treated composite was characterized by a higher compact structure than that obtained for the untreated composite. Adding of aluminum silicate to the treated composite resulted in forming minute cells throughout the composite.
4. For the results related to the dielectric properties of the banana fiber–polyurethane composite that treated by maleic anhy-

dride, the dielectric constant (ε') showed an increase whereas dielectric loss (ε'') showed a decrease indicating enhancements of its dielectric properties. Abrupt change can be seen in ε' for the treated composite on adding 10% of aluminum silicate so that at this concentration, incorporation of particle size treated composite can be occurred.

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