A STUDY OF THE ac ELECTRICAL PROPERTIES OF PURE POLYPROPYLENE AND POLYPROPYLENE-TALC COMPOSITES

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Abstract

This study reports the ac electrical properties of insulating polymers like polypropylene (PP) and polypropylene – talc composites. Polypropylene \([-\text{CH}_2-\text{CH}_2-\text{CH}_2-]\) is known as industrial polymer and Hydrous Magnesium Silicate \(\text{Mg}_3\text{SiO}_4\text{OH}_2\) commercially known as talc is a natural mineral having insulating property and these two materials are mixed with different proportion by a fabricated extrusion machine to make PP-Talc composites. To study the ac electrical properties of composites in detail, dielectric constant, loss tangent (\(\tan \delta\)) and ac conductivity were measured by a dielectric loss measurement set. The measurements were performed over a wide range of frequency of 60 Hz to 3 MHz and a temperature range from room temperature to near softening point temperature of the composites. Experimental results of the electrical properties of pure polypropylene and polypropylene-talc composites were compared and it has been established that the fabricated composites do not show any better insulating property than that of pure Polypropylene.

Introduction

During the last few years investigations were made on the structural, electrical, dielectric, mechanical and optical properties of different types of polymer composites and blends. Newspaper fiber-reinforced polypropylene composites were made by applying newspaper sheet directly to polypropylene by Shan Ren and Devid N.S.Hons. Experimental result revealed that the composites made from this method were twice as strong as the polypropylene without newspaper. M. Gahleiner et al. presented a comparative study of electrical and mechanical properties of PP with talc as mineral filler. The determinations of linear viscoelastic properties provide a quick and reliable way to investigate filler properties, dispersion and quality. The complex dielectric constant of Rochelle salt and Ammonium Rochelle salt mixed crystals in microwave region was measured by A. Oka. It was found that the mean field approximation was valid and the elementary process of the relaxation was changed successively with concentration. Plasma polymerized m-xylene thin film was prepared on glass substrate and their ac electrical properties were investigated by O. Islam in 1992. The dependence of conductance and capacitance of the films on frequency and temperature was found to obey \(\sigma(\omega) = A \omega^n\) power law. Capacitance decreases with the increase of temperature. Electrical properties of Polymer Blend with LDPE and Nylon-6 were measured by N. Shahin in 1993. It was found that ac conductivity for LDPE is lower than that of Nylon-6.

The polymers usually behave as insulators having conductivity of the order of \(10^{-14}\) (mho/cm). They have high degree of toughness, flexibility and can be molded at higher
temperature. For this reason some polymers have high resistivity, high dielectric breakdown strength. These kinds of polymers are used as electrical insulation. Earlier cables were insulated by "gutta percha" which is one of the polymers extracted from rubber trees. Now a days synthetic polymers like "polyethylene and polyvinyl chloride " are used for insulation, even for the insulation of more demanding applications of insulating co-axial cables for radar and television. The present work is an attempt to investigate PP-talc composites as a better material as an insulator. The experimental results of the electrical properties of PP-talc composites obtained are compared with that of pure polypropylene.

Experimental

An attempt has been made to prepare PP-talc composite of different proportion of PP and talc according to (10-X) PP : X Tale [X=1,3,4,5]. Four batches of different mixing ratios (9:1), (7:3), (6:4), (5:5) and pure PP were melted separately by the fabricated extrusion machine, set up at Department of Physics, Bangladesh University of Engineering and Technology (BUET). The melted materials were then collected through a die in the form of rod. The rods were cooled in a water bath and then cut with a hacksaw to pellets. The surfaces of the pellets were polished and thus the die shape composites with different thicknesses were obtained. These specimens of composites were pressed to form compact pellets by using a hydraulic press machine at a pressure of about 5000 PSI at temperature 125°C. The surface of the pellets was then coated with Aluminum by vacuum evaporation technique (coating unit: VEQCD-EU 300S. India) at a pressure ~10⁻⁴ torr. For ohmic contact on both sides of the flat circular "Al"-deposited surfaces of the sample, connection was made by a fine Cu-wire with the help of silver paste. These Cu wires served as electrode to connect type SE-70 electrode (AS20438) of a thermostatic oven.

A type WBG-9 oscillator (AS-76182) was used as a signal source that is able to oscillate at each frequencies 30 Hz, 50 Hz, 60 Hz, 110 Hz, 330 Hz, 1KHz, 3KHz, 10KHz, 30KHz, 100KHz, 300KHz, 1MHz and 3 MHz. This apparatus is to be used in conjunctions with a type BDA null detector for the measurement on the basis of synchronous selection. For regulation of capacitance and conductance components type TR-10C dielectric loss measuring set was used. Transformer ratio arms bridges are mounted inside it for matching the frequency ranges. This unit has a capacitance measurement range of 1-200 pF with minimum scale interval of 0.01 pF. Its measurement accuracy ±3% at 15 pF and over ±1% for specimens having the thickness of 0.5 to 1.5-mm. Conductance measurement changes with frequency from mho to siemens with measurement accuracy ±(5%+0.3f×10⁻¹² S), where f is the measuring frequency in kHz and 0.3 for any frequency below 330 Hz. A type TO-19 thermostatic oven was used for variation of temperature from 25°C to 200°C with a temperature stability ±0.5°C. For loss tangent measurement accuracy is ±(10%+2×10⁻⁵ in terms of tanδ) at frequency of 330Hz to 100 kHz.

Here the value of conductance G₀ was obtained initially by adjusting the conductance ratio arms and after connecting the sample a final value of conductance G' was obtained by adjusting the conductance ratio arms. Finally the conductance Gₓ obtained by multiplying conductance ratio Gₓ and (G'-G₀). Simultaneously the value of capacitance Cₓ was obtained from the capacitance scale. From these Cₓ and Gₓ value the calculation for dielectric constant,
loss tangent and ac conductivity were performed at different frequencies and temperatures by using the following formulae:

- Dielectric constant, \( \varepsilon' = (d/A) C'_x / \varepsilon_0 \)
- Dielectric loss tangent, \( \tan \delta = G_x / 2\pi f C_x \)
- ac conductivity, \( \sigma_{ac} = (d/A) G_x \)

where \( d \) is the thickness, \( A \) is the area of sample and \( \varepsilon_0 \) is permittivity of free space.

Results and discussion

For all samples ac conductivity, dielectric constant and dielectric loss tangent measurements were carried out over a frequency range from 60 Hz to 3 MHz and at the temperature range from \( 25^\circ \)C to \( 125^\circ \)C. In these frequency and temperature ranges the ac conductivity, dielectric constant varies accordingly and are summarized in table-1.

Table 1. Comparison of conductivity and dielectric constant at various concentration ratios for PP-talc composites.

<table>
<thead>
<tr>
<th>(PP:talc)</th>
<th>Range of conductivity in (mho/cm)</th>
<th>Range of dielectric constant.</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:1</td>
<td>5.30 \times 10^{-11} to 3.82 \times 10^{-7}</td>
<td>2.920 to 3.452</td>
</tr>
<tr>
<td>7:3</td>
<td>2.88 \times 10^{-10} to 5.24 \times 10^{-7}</td>
<td>3.500 to 4.121</td>
</tr>
<tr>
<td>6:4</td>
<td>9.54 \times 10^{-11} to 6.36 \times 10^{-8}</td>
<td>3.130 to 3.688</td>
</tr>
<tr>
<td>5:5</td>
<td>4.34 \times 10^{-10} to 1.78 \times 10^{-6}</td>
<td>3.087 to 4.648</td>
</tr>
<tr>
<td>Pure PP</td>
<td>5.37 \times 10^{-11} to 1.43 \times 10^{-7}</td>
<td>2.790 to 3.145</td>
</tr>
</tbody>
</table>

The graphs for ac conductivity, dielectric constant and loss tangent against frequency at different temperatures were plotted and are presented in figure-1, 2, 3.

Log frequency versus log ac conductivity curves in fig-1a, fig-1b and fig-1c show that in polypropylene-talc composites with mixing ratios (5:5), (7:3) and pure PP, ac conductivity increases with the increase of frequency at all temperatures. Similar results obtained from remaining two PP-talc composites. In fig-2a, fig-2b and fig-2c it is seen that the ac conductivity increases with the increase of talc in polypropylene. Log frequency versus dielectric constant curves in fig-3a, fig-3b and fig-3c show that the dielectric constant decreases with the increase of frequency at all temperatures. It seems from the graphs that at a particular high frequency the dielectric constant tends to be same i.e. the dielectric constant becomes independent of frequency and temperature at very high frequency. From concentration of talc in polypropylene versus dielectric constant curves at different temperature in fig-4a, fig-4b and fig-4c it is observed that the dielectric constant increases with the increase of talc in PP. Log frequency versus loss tangent curves at different temperature in fig-5a, fig-5b and fig-5c show that the loss tangent decreases with the increase of frequency at all temperatures.

These results of ac electrical properties from the graphs of log frequency versus log ac conductivity, log frequency versus dielectric constant and log frequency versus loss tangent of PP-talc composites are in good agreement with the results of ac electrical properties of pure polypropylene.
Fig-1a. Log (frequency) versus Log (ac conductivity) curve for Sample (5:5)

Fig-1b. Log (frequency) versus Log (ac conductivity) curve for Sample (7:3)

Fig-1c. Log (frequency) versus Log (ac conductivity) curve for pure PP

Fig-2a. Concentration of Talc in PP versus Log (ac con.) at freq. 60Hz.

Fig-2b. Concentration of Talc in PP versus Log (ac con.) at freq. 3 KHz.

Fig-2c. Concentration of Talc in PP versus Log (ac con.) at freq. 1 MHz.

Fig-3a. Log (freq.) versus Dielectric constant curve for sample (5:5)

Fig-3b. Log (freq.) versus Dielectric constant curve for sample (7:3)
Therefore, it is possible to prepare Polypropylene – talc composite as a new material by the fabricated extrusion machine. The ac conductivity of composites increases with the increase of frequency, temperature and the concentration of talc in PP. The frequency and temperature
dependence of ac conductivity may be attributed to the increase of relaxation times dominated by interfacial type of mechanism. The dielectric constant decreases with frequency and temperature. This behavior may be attributed to thermal agitation, which does not allow polarization. The dielectric constant is independent of frequency and temperature at high frequency, which may be understood from the pining of dielectric. The dielectric constant increases with the increase of concentration of talc, which may be due to domination of interfacial polarization over dipole polarization. Therefore, it may be concluded that the interfacial polarization mechanism is responsible for the dielectric relaxation in the composites. The variation of loss tangent with log frequency and temperature shows a normal loss without having any α, β, γ peak.

Experimental observations suggest that it is possible to make PP-talc composites as an insulator by the fabricated extrusion machine and this is a good technique of making composites. But from the comparison of the ac electrical properties of the fabricated PP-talc composites with the ac electrical properties of the pure polypropylene it has been observed that the fabricated composites do not have better insulating property.

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References