Conduction Mechanism and Conductivity Behaviour of Pure Polypropylene (PP) and Polypropylene-Banana Fiber (PP-B) Composites

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ABSTRACT

Fibers reinforced composite materials offer a combination of strength and modulus that are either comparable to or better than many traditional metallic materials. The research on natural fiber based composite materials fit well into this ecological image. This paper reports the conduction mechanism and ac conductivity, activation energy behavior of Polypropylene and banana fiber reinforced thermoplastic composites. Polypropylene [-CH₂CH₂CH₂n] and different fiber content (wt. %) of polypropylene-banana fibers (natural fiber) composites were fabricated using a hot-press molding system. The optimum fabrication parameters were established (initial pressure, temp. etc.). These composite test samples were fabricated so the short fibers were randomly oriented in the matrix. The detail investigation of the a. c. conductivity and conduction mechanism of polymer composites would provide information about the relaxation processes, activation energy etc. which are dependent on frequency, temperature and time. The activation energy involved in the above processes can also be estimated from this study. The measurements were performed over a wide range of frequency of 60 Hz to 3 MHz and temperature range from 30°C (303°K) to 110°C (383°K). Experimental results of the ac properties of pure polypropylene and polypropylene-natural banana fiber composites were compared. It has been established that the fabricated composition changes its insulating property after adding the natural fibers and gives the better conductivity properties.

1. Introduction

It is a modern trend that every material should be environment friendly. So it is essential to develop and use biodegradable materials due to increasing environmental consciousness of legislative authority. A large number of natural fibers are locally available. Use of these fibers as reinforcing materials increases the bio-degradability, reduces cost, and decreases pollution and hazard, but it requires rigorous research work. It would be very interesting if natural fibers (like jute, coir, banana, sisal, etc.) could be used instead of artificial fibers and synthetic products as reinforcement in some technological and structural applications. Fibers reinforced composite materials offer a combination of strength and modulus that are either comparable to or better than many traditional
metallic materials. This is because of their highest specific strength and densities compared with inorganic fibers and reinforcements.

Available local natural fibers are the most common reinforcing fibers for polymer matrix composites due to their low cost and high electrical resistance and are used in many high-volume applications. They can be used as reinforcing fibers due to their biodegrading and environment-friendly characteristics. These polymer-natural fiber composites can be used as electrical device and dielectric materials. The electrical conduction in polyethylene, a polymer having major use in cable industry, has been investigated as a functional of applied electric field and thickness by S. Sing and H.P. Sing [3]. Where the conduction was found to be ohmic in low field (400KV/m) and space charge limited in intermediate fields (400-1600KV/m). Applying newspaper sheet directly to polypropylene [3]. These products have a greater prospect in their use in material applications where relative low density of the natural fibers is a major advantage. Similar experimental result revealed that the composites made from hot press molding method were twice as strong as the polypropylene without newspaper. Abdullah and Das – Gupta [4] studied the electrical, dielectric and pyroelectric properties of three types of ceramic polymer composites. Where the dielectric loss tangent of the ceramic-polymer composites was observed to be dominated those of the polymer, while the ceramic phase may have a significant conduction on the steady state electrical conduction and low frequency dielectric loss at high temperature. M. Gahleiner et al. [5] presented a comparative study of electrical and mechanical properties of PP with talk as mineral filler. Electrical properties of coir-fiber reinforced low density polyethylene composites was measured by Paul Augustine [6]. It was found that electrical conductivity and dielectric constant increases with the increase of fiber mixing and decreased with the increase of frequency for all composites. The vol. resistivity decreases with the increase of fiber content. Characteristics of natural fiber reinforced polyurethane composites were done by De Araujo, Carla Reis [7]. Composites with coir fiber or bagasse of sugarcane (B.Sc.) were prepared by melt mixing method. The result shows thermal resistance of both composites of different properties was similar with onset around 573°K. Electrical properties of polymer blend with LDPE and Nylon - 7 were measured by N. Shahin [8] in 1993. It was observed that ac conductivity for LDPE slower than Nylon-6. The electrical properties i.e. volume resistivity dielectric permittivity and dielectric loss factor as well as thermally stimulated depolarization current were measured on PP – polycarbonate (PC) blends by P. Myslinski et al. [9]. The results confirmed the existence of some interactions between the non compatible components of PP-PC blends. It was observed that the volume resistivity varies proportionally to the blend composition. The polymers usually behave as insulating materials having resistivity of the order of $10^{-14}$ Ω-m. They have high degree of toughness flexibility and can be molded at higher temperature. Due to this reason some polymers have high resistivity, high dielectric breakdown strength.

2. Experimental

2.1 Materials

PP was collected from local market. Banana fibers were collected locally. All these fibers were chopped and kept at 383°K for 24 hours for moisture free. For getting uniform length, all these fibers were sieved by 2 mm sieve. PP matrix materials were also taken as moisture free at the same procedure.

2.2 Sample Preparation

2.2.1 Fiber Cutting and Mixing

All the fibers were collected locally and chopped by a sharp knife and sieve by 2 mm sieve to get uniform fiber. This fiber kept at a dry environment (oven) for 24 hours at 383°K. Fiber and polymer were thoroughly mixed using a blender. The mixing time and blade speeds were 2 minutes and 400 rpm respectively. For uniform mixing this process was repeated 3 times and the intermingled fibers are separated manually.

2.2.2 Casting, Molding and Demolding

A steel device is made to very close tolerance for the molding process. The mixture of fiber and matrix is cast by simply pouring the mixture into the mold and leveling it to the desired thickness. Only slight stamping or hammering on the mold is required for sufficient compaction. Both mixed fibers and polymer were taken in a mold. An initial of 50 KN pressure over the sample area was given to top of the mold and then the mold was kept in a P/O/ Weber Pressen Hydraulic Machine. The applied pressure is measured by using a load cell, set in the device. Heating was done electrically and the temperature set at 453°K. Only 25-30 minutes were required to reach such temperature. The temperature was kept at 453°K for 20 minutes. After completion of heating the final pressure of 50 KN over the sample area was set to avoid the kind of voids and have a desired thickness. This additional pressure was kept for one hour. An attempt has been made to prepare PP-fiber composite of different proportion of PP and fiber according to (100-X) PP: X Fiber [X= 0, 10,20,25]. Four
batches of different mixing ratios (100:0), (90:10), (80:20),
(75:25) were used. The percentage (%) of fibers was taken as 0, 10, 20, and 25 of total 100 gm of composites for the fabrication of PP & banana fiber composites. Cooling was done by water flow through the outer area of the heating plates of the hydraulic press machine for 25 minutes.

When the Weber Pressen hydraulic machine is made the specimen. The specimen was cooling, the specimen adheres very strongly with the mold; the makeshift device did require removing by a set up device, which is made as a makeshift device. After separation of the composites from the device. After cooling and de-molding, the prepared samples were then made in a circular shape to form compact pellets of diameter 8 mm to.01m by cork-borer with heavy pressure.

2.3 Testing Procedure

For ohmic contact both sides of the prepared samples were polished by sand paper and coated with silver paste. The ac. conductivity and dielectric properties have been measured using a Wayne Keer B224 Universal (transformer ratio arm) bridge. The ac conductivity with frequency and frequency of PP and PP-B are calculated from the measured data. These parameters have been measured at temperatures of 303, 343,363K as a function of frequencies of 60Hz 10 KHz, 1 MHz and 3 MHz. The sample temperature, during the experiment PID thermostatic Oven (SE-70, electrode AS 2048) containing the sample holder which is connected with proper screening to the measuring electrodes, in instruction manual. All these measurements were taken 4 times for each batch and average values were considered. In this measurement there were no major variations with in individual data.

Here the value of conductance G\text{c} was obtained initially by adjusting the conductance ratio arms and after connecting the sample a final value of conductance G\text{f} was obtained by adjusting the conductance ration arms. Finally, the conductance G\text{r} was obtained conductance ration G\text{r} and (G\text{f}-G\text{c}). AC conductivity were performed at different frequencies and temperatures by using the following formulae: 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.

3. Results and Discussion

3.1 Ac Conductivity

Log ac conductivity vs log frequency curves at different temperatures are shown in Figure 1(a), 1(b), 1(c), 1(d) for the temperatures of 303°K, 343°K, 363°K and 383°K respectively. It is observed that ac conductivity increases with frequency and fiber content (wt.%) of the composites and also with the working temperatures for all the samples. This kind of behavior of electrical conductivity with frequency has been reported for different polymers in the literature \cite{10}. Pure PP exhibits very small electrical conductivity. The addition of fiber in PP may significantly increase the electrical conductivity.

![Figure 1(a). effect of frequency on ac conductivity for banana fiber composites at 30°C](image1)

![Figure 1(b). effect of frequency on ac conductivity PP &PP-for PP& PP-banana fiber at 70°C](image2)

![Figure 1(c). effect of frequency on ac conductivity for PP& PP-banana fiber composites at 90°C](image3)
Figure 1(d). effect of frequency on ac conductivity for pp & pp-banana composites at 110°C

It is seen that the ac electrical conductivity of the composites increases as the concentration of fiber increases. It might be due to increase of polar groups in the composites, dipole originating from the presence of asymmetric excess electron in the polymers. So, it is obvious that as the polar molecules concentration increases, the number of electrical charge carriers increase resulting in higher conductivity by Umemura et al [11].

It is also observed that ac conductivity decreases with the increase of temperature up to 363K and then remains almost constant in the composites at all frequencies as shown in Figure 1(e), 1(f) for the samples of PP-B. It is interesting to note that the conductivity becomes less dependence on frequency in going from lower to higher temperatures. Thus, it becomes apparent that the conductivity is more temperature dependent. This decrease in conductivity with increasing temperature may be attributed to the removal of moisture content from the samples. Above 363K moisture removal becomes insignificant and hence conductivity becomes constant. Above the temperature 363 K, moisture or water content elements are dropped out. Thus, it becomes apparent that the conductivity is temperature dependent. This feature can be attributed to the dominating contribution of interfacial polarization in the composites with higher fiber concentration. Similar result was observed by Krasaz [12]. The relation may describe such dependence is given by $s_a \omega^n$. The values of the exponent n were derived from the slopes of logarithmic conductivity verses different frequencies. It is seen that $s_a \omega^n$ varies as $\omega$ with $n = 0.44-1.0$ for lower and higher frequency regions at all the temperatures for PP-B samples.

The describe values of $n$ were less than unity (shown in Table 1) for all temperature ranges may be attributed to the decreases of distribution of relaxation times dominated by interfacial type of mechanism. Similar result was observed by Arauji and Reis [7]. Electrical conduction in these composites is probably due to both ions and electrons. This conductivity dependence on frequency is an indication of hopping conduction. A similar frequency dependence of the ac conductivity in Zn-PC has been observed by Saleh et al [13].

| Description of the materials | Temperature in k | The value of n at 330 Hz | The value of n at 3 MHz |
|-----------------------------|-----------------|--------------------------|------------------------|
| PP                          | 303             | 1.25                     | 1.01                   |
|                             | 343             | 0.88                     | 0.96                   |
|                             | 363             | 0.66                     | 0.85                   |
|                             | 383             | 0.54                     | 0.80                   |
| 10% PP-B                    | 303             | 0.98                     | 0.99                   |
|                             | 343             | 0.77                     | 0.89                   |
|                             | 363             | 0.64                     | 0.75                   |
|                             | 338             | 0.44                     | 0.52                   |
| 20% PP-B                    | 303             | 0.99                     | 0.85                   |
|                             | 343             | 0.80                     | 0.72                   |
|                             | 363             | 0.75                     | 0.61                   |
|                             | 338             | 0.45                     | 1                      |

Table 1. n values for all samples of PP and PP-B samples
Table 2. Activations energies at low and high frequency regions for PP, PP-B composites.

| Description of the materials | Frequency region | Activation energy Kcal/Mole |
|-----------------------------|------------------|-----------------------------|
| PP                          | Low              | 4.93                        |
|                             | High             | 8.32                        |
| 10% PP-B                    | Low              | 7.714                       |
|                             | High             | 10.56                       |
| 20% PP-B                    | Low              | 5.43                        |
|                             | High             | 6.39                        |
| 25% PP-B                    | Low              | 6.63                        |
|                             | High             | 6.78                        |

Figure 2. Log $\sigma_a$ (ohm-m)-1 vs inverse of Kelvin temp. graph for PP and PP-B composites at low and high frequency.

The activation energies for all composites at low and high frequencies are given in Table 2. This may be due to restriction of ion jump for higher concentration of fiber in PP. The differences in activation energies become less with the increase of concentration of fiber in the matrix. The activation energies can be obtained from the slope of the linear portion of $\log \sigma_a$ against $(1/T) \times 10^4$ plots for low and high frequency region as shown in Figure 2. It is observed that the enhancement of activation energy in going from low to high frequency may arise due to the ion - jump mechanism. The activation energies for all composites at low and high frequencies are given in Table 2.

4. Conclusions

The ac electrical conductivity of the composites increases as the concentration of banana fiber increases in PP. It is also observed that ac conductivity decreases with the increase of temperature up to 363K and then remains almost constant in the composites at all frequencies. The frequency and temperature dependence of $\sigma_a$ may be attributed to the increases of relaxation times dominated by interfacial type of mechanism. This feature can be attributed to the dominating contribution of interfacial polarization in the composites with higher fiber concentration. which indicates that fiber act as an intermediate plasticizer in the composites. The differences in activation energies become less with the increase of concentration of fiber in the matrix. Experimental observations suggest that it is possible to make PP-banana fiber composites by the hot-press molding method and these composites can be used in the manufacture of high frequency electrical device. This fabrication technique may also be applied to prepare the dielectric material for the preparation of capacitor and other electrical devices.

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