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Influence of Talc Filler Content on the Mechanical and DC Electrical Behavior of Compression Molded Isotactic Polypropylene Composites

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Abstract Isotactic polypropylene(iPP) and iPP-talc composites with compositions of 9:1, 8:2, 7:3, 6:4, 5:5 wt. ratio were prepared by extrusion cum compression molding methods. Various mechanical properties such as Young modulus (YM), tensile strength (TS), elongation- at -break (EB%), flexural strength (FS), flexural modulus (FM) and electrical behavior of these composites were investigated. YM of iPP-talc composites increases with the increase of talc content whereas TS and EB (%) of the composites decrease with talc content. The YM value of the composites with 30 wt% talc is the highest. The FS increases with the addition of talc up to 30 wt% and above this it decreases. But flexural break (%) decreases with the increase of talc content. FM increases slowly up to 20 wt% talc and then it increases rapidly for 30 wt% talc. The current-voltage (I-V) characteristics of the composites were recorded in the voltage range from 0 to 120 V DC at different temperatures. It is evident that I-V curves show ohmic behavior in the lower voltage region and in the higher voltage region the contact is non ohmic, which suggests that the current may be due to space charge limited conduction (SCLC) for iPP and Schottky or Poole–Frenkel (PF) conduction mechanisms in iPP-talc composites. Electrical conductivity is found to increase with increasing temperature but it decreases with the increase of talc content for these composites. The activation energy of all the samples has higher value in high temperature region than those at low temperature region.

Keywords Isotactic polypropylene – talc composites, Mechanical properties, Electrical behavior

1. Introduction

In comparison with metals, polymers can offer better processing, a lower density, a higher strength-to weight ratio, better resistance to corrosion, and often a better price/performance ratio. A current increased demand for applications of synthetic polymers in the automotive and aeronautic industries is evident, mainly in the utilization of polyethylene, polypropylene (PP), polycarbonate, and polyamide components in the interior, exterior, and other functional parts of the vehicle [1].

Isotactic polypropylene (iPP) is becoming one of the most important commodity polymers, widely used in technical appli cations. Because of its intrinsic properties, such as a high melting temperature, low density, high chemical inertness and the capability of being toughened with elastomers, iPP has found a wide range of applications in the food packaging, electrical, and automotive industries. Moreover, iPP is one of the most favorable matrices for high-volume, low-cost composites and blends [2]. Its applications are greatly extended by adding inorganic fillers such as talc, calcium carbonate, mica, glass, etc to improve mechanical properties, thermal resistance, and dimensional stability, all at a low cost [3].

This study is focused to reinforcement of iPP with the addition of the mineral talc. Talc is a hydrated magnesium silicatemineral having the chemical formula [$Mg_3Si_4O_{10}(OH)_2$], widely used in polymers as a reinforcing filler. Talc contains 31.7% MgO, 63.5% SiO_2 and 4.8% H_2O. Talc deposits are probably formed by hydrothermal attention or contact meta morphism of preexisting rocks. Its plate-like structure provide the talc filled materials with tailored properties to be used in some industrial and commercial applications such as in refrigerators jackets, packaged components, blocking of infrared radiation in agricultural films, and in automotive and appliance markets. Talc filled iPP composite has low specific gravity and combines excellent chemical resistance with low cost [4]. Researchers around the world work to develop both new composite materials and also improve existing ones. A large no of research works has been dedicated to improve the properties

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and quality of composite materials to meet engineering requirements. Shrinkage behavior and mechanical performances of injection molded iPP/talc composites were studied by Shelesh-NezhadK and Taghizadeh A [5]. The results of experiments indicated that the maximum flexural strength (FS), maximum impact strength, and isotropic shrinkage were achieved by adding 10, 20, and 30 wt% of talc respectively. By incorporating of 10 wt% of talc particles into the PP matrix, the tensile strength (TS) was hardly affected. Mechanical properties of intercalated talc/ polypropylene nanocomposites with different wt% of talc prepared by an injection- molding machine were analyzed by Mashael Alshabanat [6]. TS and impact properties have been studied as a function of talc content. The results suggested that there is an optimum talc content for enhancement of the TS of the composites. With a further increase in talc content, a decrease in TS was observed. Shammya Afroze et al [7] investigated elastic and electrical properties of graphite and talc filler reinforced polypropylene composites. The TS of the composites decreases with the increase of filler addition and also with the increase of wt.% of filler. But, a slight improvement of the Young's modulus (YM) of the composites with different wt.% of filler is observed. Considering practical and technological importance of composites, this study is focused the influence of talc on the mechanical properties [YM, TS, elongation at break (EB%), FS , flexural break (FB%), flexural modulus (FM)] and dc electrical behavior of compression molded iPP/talc composites.

2. Experimental Details

2.1. Materials Used

Composites used in this work were prepared from iPP and talc. Commercial grade iPP was purchased from BASF, Germany. The density of iPP is 0.91 g/cc and Its melting temperature is 438 K. Talc is collected from local market and is in the form of powder. The density of talc is 0.56g/cc and melting temperature 1073 K.

2.2. Sample Preparation

At first, five different composites were prepared by iPP and talc powder according to the ratio (10-X) PP: X talc, where X =1, 2, 3, 4, 5. Besides these one pure iPP sample was also prepared. The mixtures were kept in separate pot and then mixed uniformly as much as possible. The different mixtures were melted by extrusion machine. Three heaters of extrusion machine were switched 'ON' for about one hour. The barrel was heated for about one hour at 513 K. After heating for one hour the mixture was put into the feed hopper. The motor was then switched on to feed the batch from the feed hopper into the barrel. The molten composite material was then collected through the die in the form of rod. These were cooled in a water bath during collection. The rods were then cut with a hexsaw. For converting the rod shape samples into disc shape sample 450 kN Weber-Press machine were used. The heating temperature and initial pressure were set at 180°C and 50kN respectively. After reaching the set temperature, the pressure was increased up to 100 kN and the heating system was stopped.

2.3. Measurements

2.3.1. Mechanical Testing

To evaluate the mechanical properties of prepared composites, tensile and flexural testing were performed. For the mechanical testing of the samples a universal testing machine (Hounsfield UTM 10KN) was used. Tensile specimen was prepared according to (ASTM D-638M-91) [8] at a crosshead speed of 1 mm/min. Flexural specimen was prepared according to (ASTM D790M) [9], 3 point loading. The specimen dimension was (80m × 10m × 3m) and support span was 64 mm. The crosshead speed was taken as 2 mm/min. At each composite composition at least five samples were tested and the average result were reported. All the measurements of mechanical (tensile and flexural) properties are carried out at 30°C temperature.

2.3.2. Electrical Measurements

In electrical measurements, silver paste coated sample was placed in between the electrodes inside the specimen chamber. The chamber was evacuated using a rotary vacuum pump to about 10^{-2} torr. Then a 614 Keithley electrometer and stabilized d.c. power supply were connected in series with the specimen. In case of current-voltage (I-V) measurements, to record the dc current through the sample at different applied voltages at constant temperature, the electrometer was set in the current mode. In this case the voltage was varied from 0 to 120 V. The current was recorded every 5 V interval. In case of current- temperature (I-T) measurements, the electrometer was set in current mode for the direct measurement of current at different temperature at a constant voltage. To raise the temperature, the specimen chamber was heated by a heating tape which can be easily wrapped around the specimen chamber. The sample current, I was measured at every 0.2 mV increase of thermocouple reading. The data were recorded from room temperature to 398K for different samples. After annealing, the above procedure of I-T measurements were applied for every sample to investigate the changes.

In this experiment, V is the applied voltage and I is the corresponding current through the sample. The slope from the I-V characteristics can be found as follows,

$$I \propto V'' \tag{1}$$

$$n = \frac{\Delta log I}{\Delta log V} \tag{2}$$

where n is the power factor, when n = 1, then it follows the ohm's law.

The current can be written as

$$I = I_0 \exp(-\frac{E_T}{kT}) \tag{3}$$

The activation energy E_T can readily be evaluated from the slope of the linear lnI vs 1/T plot, which describes the nature and type of carrier involve in the conduction process.

3. Results and Discussion

3.1. Mechanical Properties

3.1.1. Tensile Properties

Figure 1(a) shows the effect of talc addition on YM of iPP-talc composites. It exhibits that the YM of the composites increases with the increase of talc content up to 30 wt% after that it decreases. The maximum value of YM is 2024.4 MPa for composites with 30 wt% talc. Reason of increasing YM, talc and iPP are well distributed up to 30 wt%. YM is a measure of stiffness of a material. Thus stiffness of these composites increases with the increase of talc content up to 30 wt%. The reason of decreasing YM for 40 and 50 wt% talc is probably due to interfacial adhesion between the talc particles and the iPP matrix becoming weaker on increasing the talc after a critical filler content, whereupon the filler particles start to form agglomerates. These agglomerates constitute flaws and become larger in size, resulting in voids between the filler particles and the matrix is such that adhesion at the interface becomes poor [10]. Such increase of YM in PP-talc and iPP-white clay composites were observed by TJong SC et al [2], and Mina Forhad et al [11] respectively.

With increasing talc content the variation of TS of these composites is shown in Figure 1(b). It reveals that the TS of composites decreases with the increase of talc content. The TS value of original iPP is 30.10 MPa. The reason is that the crystalline behavior of iPP is high. Addition of fillers reduces the crystallinity and chain mobility of iPP and TS decreases continuously. Similar effect (with the increase of fibre content and diamond, the TS of fibre- copper powder filled low density polyethylene and diamond-epoxy composites decreases respectively) was found by Muniruzzaman M [12] and J.R.M d'Almeida [13] respectively. The reason is that the stress transfer to the particle is not being properly achived and fibres coagulated as a bundle and the bundle gets fractured during load to slips and does not make resistance to slips consequently the TS would decrease. The results for EB % are shown in Figure 1(c). It is observed that the EB (%) decreases with the increase of talc content. The EB% for iPP was found to be 25.80%. iPP has a high value of EB, because when force is applied, the polymer chains have enough space and time to orientate, which is the result of the chemical structure of iPP. Immediately when the chains are oriented, they start to form orientation crystallinity, which evokes an increase in the strength of the sample. Adding filler to the polymer matrix reduces chain mobility and restricts the slip resulting in less ductility and consequently the EB % decreases with the increase of talc addition. Similar effect (with the increase of Cu powder and talc content, the EB% of Cu powder-LDPE and LLDPE, PP-talc composites decreases respectively) was found by Luyt AS [14] and Tao Wang [3].

3.1.2. Flexural Properties

Flexural performance of iPP-talc composite with increasing talc content is shown in Fig 5. It reveals that with the increase of talc content, FS and FM increases [Figure 2(a) & 2(b)]. [The maximum FS was obtained by adding 30 wt% of talc. The FM increases slowly up to 20 wt% talc and then quickly for 30 wt% talc. Addition of 40 wt% and more of talc filler in these composites brittleness increases and hence reduction of FS occurs. Similar effect was found by Moniruzzaman M [12]. With the increase of fibre, the FS of fibre-LDPE composites increases. Figure 2(c) shows the effect of talc addition on flexural break (FB%) of PP-talc composites. It is seen that FB (%) of composites decreases with the increase of talc content.

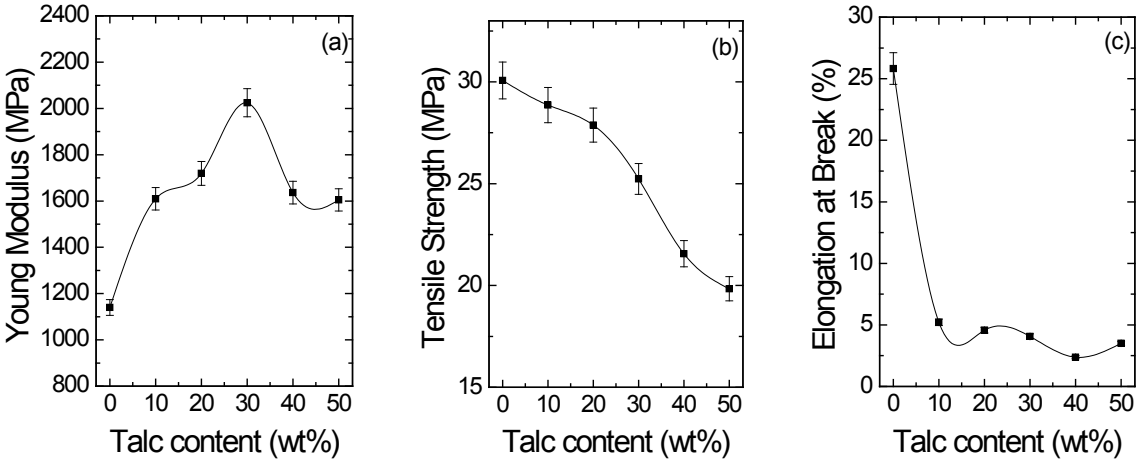

Figure 1. Variations of (a) Young's modulus, (b) tensile strength and (c) elongation at break (%) with increasing talc content for the PP-talc composites

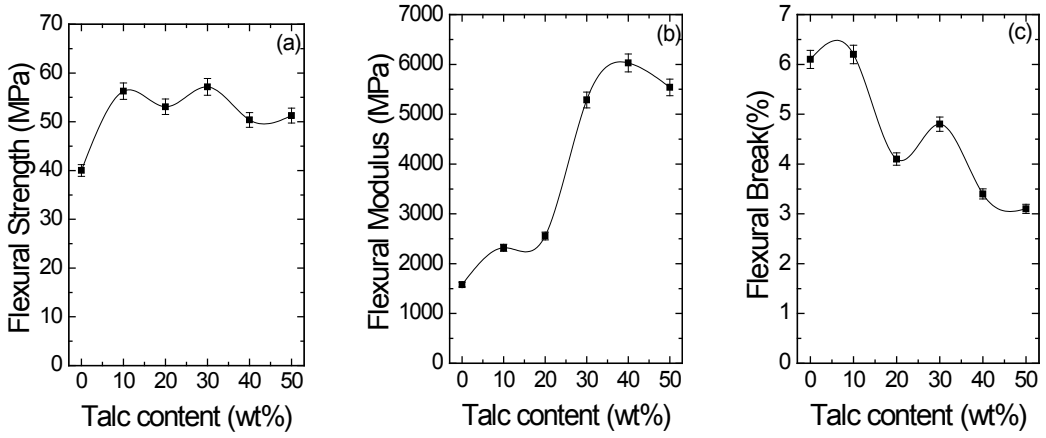

Figure 2. Flexural performance of PP-talc composite with increasing talc content (a) flexural strength (b) flexural modulus (c) flexural break (%)

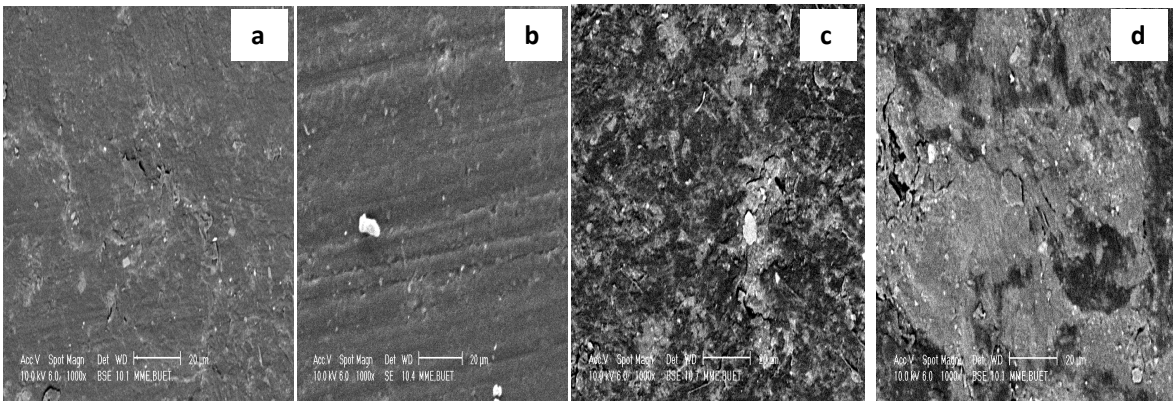

Figure 3. The SEM micrographs of (a) iPP (b) 20 wt% (c) 30 wt% and (d) 50 wt% iPP- talc composites

Finally, these mechanical analysis are also supported by SEM study. The SEM micrographs of iPP and composites with 20, 30, and 50 wt% talc content are shown in figure 3. It is observed that the surface structure changes due to the percentage of talc in iPP. It can also be seen from micrographs that iPP, 20 and 30Wt % talc surface is smooth in comparison to 50 Wt % talc composites. It is also observed that talc is dispersed uniformly in the matrix and this uniform dispersion is not decreased even with talc content as high as 30wt% talc. On the surface of the composites of 50 Wt % talc contain more crack, void, agglomerates or larger particles.

3.2. DC Electrical Properties

3.2.1. Current-Voltage (I-V) Characteristics

The I-V characteristics of iPP and iPP-talc composites with different wt% of talc at different temperatures (30°C, 60°C and 90°C) are shown in Figure 4. These I-V curves follow a power law of the form of equation (1) with different slopes in the lower and higher voltage regions, where n is a power index. It is observed that with the increase of voltage, current increases gradually at low voltage and faster at high voltage and it is also observed that with the increase of % of talc the current decreases. In the lower voltage region the values of slope n of I-V curves of all the samples are 0.8o < n < 1.2, which lies around unity. So the contact is found to be ohmic for all the samples. In the higher voltage region n values for iPP-talc composites are $1.01 < n < 1.55$ and for pure iPP that is 2.62. This means that the contact is non ohmic, which suggests that the current may be due to SCLC for iPP and Schottky or Poole– Frenkel (PF) conduction mechanisms in iPP-talc composites [15].

Figure 5 shows variation of electrical conductivity at room temperature with different filler concentration in iPP. This figure reveals that the electrical conductivity of iPP-talc composites decreases up to 20 wt% talc and then higher concentration of talc much less effect on the conductivity.

3.2.2. Current-Temperature (I-T) Characteristics

The current was measured for PP-talc composites in the temperature range from 298K to 363K at an applied voltage of 100 V. The plots of conductivity (s) vs temperature for iPP-talc composites are shown in figure 6. In figure 6, it is observed that electrical conductivity increases slowly with increasing temperature in the lower temperature region (298-323K) and at high temperature region (323-363K) electrical conductivity increases rapidly with increasing temperature. It is also observed that with the addition of talc with iPP electrical conductivity decreases. The increase of conductivity with temperature may be due to the increased

movement of the adventitious ions or electrons. The carriers experience a thermal velocity due to the increase in temperature in addition to the applied electric field which was kept constant at 100 V. So the resultant velocity experienced by the carriers is the sum of the drift velocity and the thermal velocity. In this study, thermal velocity is changed due to the increase in temperature. Such increase of conductivity with increasing temperature in liquid crystalline polymer filled carbon black and PP filled Bijoypur white clay was observed by Wong et al [16] and Razzak et al [17] respectively.

The activation energy (E_T) for the samples was determined from figure 6 using eq^n (3). The values of E_T associated with two temperature regions of all the samples are depicted in table 1. The E_T of all the samples has higher value in high temperature region than those at low temperature region.

Table 1. Values of Activation Energy for Different Samples

Samples	Activation energy E_T (eV) at (298-323)K	Activation energy E_T (eV) at (323-363)K
PP	0.04	0.14
Composites with 10% talc	0.13	0.33
Composites with 20% talc	0.17	0.37
Composites with 30% talc	0.11	0.39
Composites with 40% talc	0.04	0.73
Composites with 50% talc	0.13	0.7

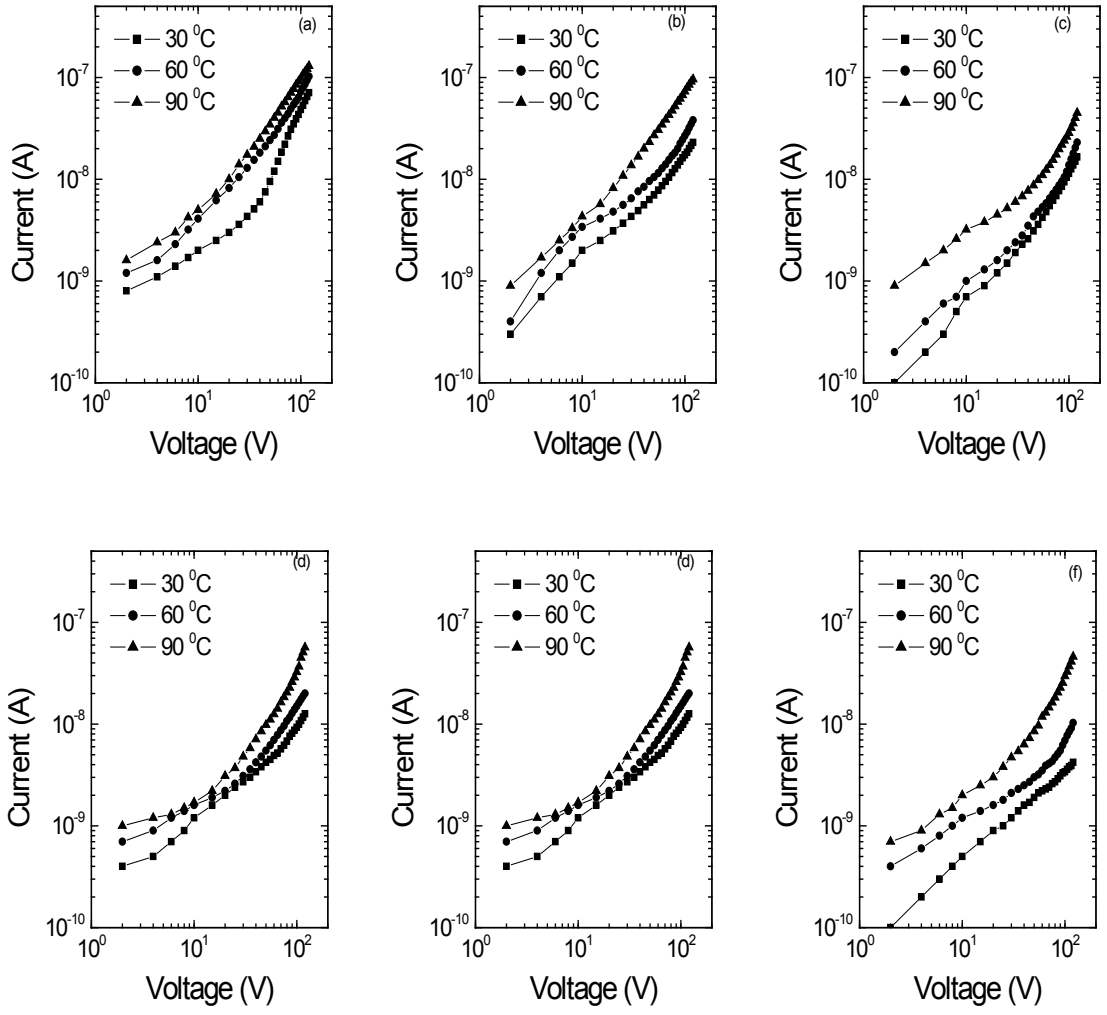

Figure 4. The I-V characteristics of (a) iPP (b) 10% ((c) 20%) (d) 30% (e) 40% (f) 50% talc content at different (30°C, 60°C and 90°C) temperatures

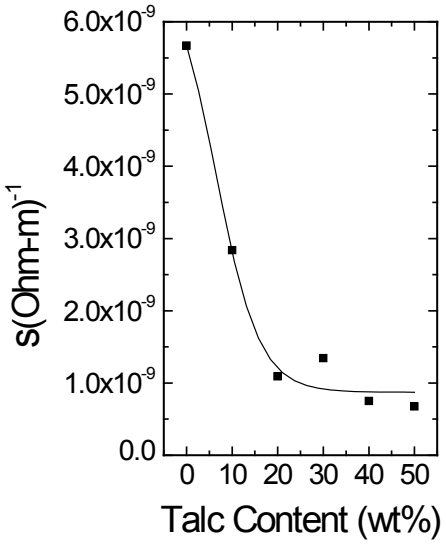

Figure 5. Effect of talc on conductivity at 30°C and 50 V of iPP-talc composites

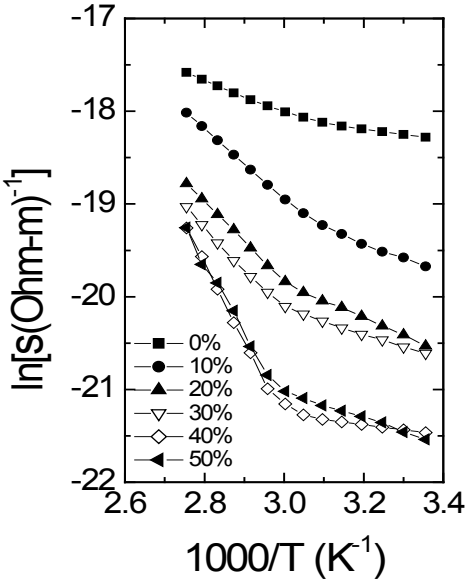

Figure 6. Effect of talc content on lns vs 1/T at 100 V for PP-talc composites

These low values of E_T for all the samples implies that the existence of thermally activated hoping conduction in these materials .In these type of conduction process the carrier may be bound to agglomerates itself. As a result the carrier may not take part in the conduction thought the bulk of the composites.

4. Conclusions

In this research, the mechanical and electrical properties of iPP-talc composites were investigated. With the increase of talc content, YM increases but the TS and EB% of composite decreases. The value of YM is maximum for 30 wt% talc. On the basis of the elastic modulus it appear that the talc filler can be used as an effictive reinfocement for these composites for up to 30 wt%. The FS and FM increase with the addition of talc up to 20 to 30 wt%. The maximum value of FS is 57.151 MPa for 30% talc. FB % of composites decreases with the increase of talc content. It is observed that I-V curve shows ohmic behavior in the lower temperature region. With the increase of talc the conductivity of these composites decreases up to 30 wt% of talc.

The mechanical and electrical test result suggested that 30 wt% is an optimum talc concentration at which these composites has improved mechanical properties. So iPP with 30 wt% talc can be used for industrial and scientific application.

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