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The D.C and A.C Electrical Properties of (PMMA -Al_2O_3) Composites

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Abstract

The D.C and A.C electrical conductivity of (poly-methyl methacrylate - alumina) composite has been investigated. For that purpose, the PMMA samples with Al_2O_3 additive prepared with different percentages(0,15,25,35 and 45) wt.% and different thickness. The experimental results showed that the D.C electrical conductivity increased with increasing the alumina concentrations and temperature. Also the activation energy change with increasing of additional alumina. The dielectric constant, dielectric loss, A.C electrical conductivity are changed with change the concentration of the filler and frequency of applied electrical field.

Keywords: Composites, poly-methyl methacrylate, Electrical Properties.

Introduction

In order to fulfill the requirements of polymer industry many developers usually blend polymers together in order to reach an optimum balance of properties, this approach allows high flexibility in property adjustment and avoids development of new macromolecules which is generally long and expensive compared to polymer alloying [Mohammed, 2007]. A vigorous development of polymer composite and extensive utilization of polymer materials in technology have led to the polymer composites [Wenderlinch;1973]. The importance of polymers is mainly because polymers are still regarded as a cheap alternative material that is manufactured easily. The intensive use of polymer in broad use has led to the development of materials for specific applications namely composites [Comelio *et al*, 1996]. Recently polymer matrix-ceramic filler composites receive increased attention due to their interesting electrical and electronic properties, Integrated decoupling capacitors, angular acceleration accelerometers, acoustic emission sensors and electronic packaging are some potential applications. Ceramic materials are typically brittle, possess low dielectric strength and in many cases are difficult to be processed requiring high temperature. On the other hand, polymers are flexible, can be easily processed at low temperatures and exhibit high dielectric break down fields[kontos, *et al* , 2007]. Ahmed and Marwa, in(2010) studied the effect of Lithium Fluoride content on D.C electrical properties of poly-methyl methacrylate. The D.C electrical conductivity of the PMMA increased by increasing of LiF concentrations and temperature. The activation energy decrease with increasing filler concentration The present work deals with the effect of alumina additive on the D.C and A.C electrical properties of poly-methyl methacrylate composite.

Experimental Work

The materials used in the paper is poly-methyl methacrylate as matrix and alumina as a filler. The electronic balanced of accuracy 10^{-4} have been used to obtain a weight amount of alumina powder and polymer powder .These mixed by Hand Lay up and the Microscopic Examination used to obtain homogenized mixture .The weight percentages of Al_2O_3 are (0, 15,25,35 and 45) wt.%. The Hot Press method used to press the powder mixture. The mixture of different Al_2O_3 percentages has been compacted at temperature 165°C under a pressure 100 bar for 10 minutes . Its cooled to room temperature , the samples were disc shape of a diameter about 15mm and thickness ranged between (1.08-1.32)mm. The coating unit (Edward coating System E3C6A) has been used for deposition of thin film Aluminum electrode on both sides of each sample . The resistivity was measured over range of temperature from (30 to 70)°C using Keithly electrometer type (616C) .The volume electrical conductivity σ_v defined by :

$$\sigma_v = \frac{1}{\rho_v} = \frac{L}{RA} \qquad (1)$$

Where :

A = guard electrode effective area.

R = volume resistance (Ohm) .

L = average thickness of sample (cm) .

In this model the electrodes have circular area A= $D^2\pi/4$ where D= 0.5 cm^2 .

The dielectric properties of PMMA- Al_2O_3 composites were measured using (Agilent impedance analyzer 4294A).

In the frequency(f) range (25×10^2-5×10^6) Hz at room temperature. The measured capacitance, C(w) was used to calculate the dielectric constant ,έ(w) using the following expression:

$$\acute{\varepsilon}(w) = C(w)\,\frac{d}{\varepsilon_o A} \qquad (2)$$

Where d is sample thickness and A is surface area of the sample . whereas for dielectric loss ε"(w):

$$\varepsilon''(w) = \acute{\varepsilon}(w) \times \tan\delta(w) \qquad (3)$$

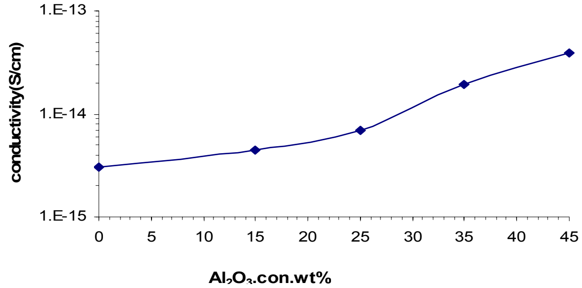
Where tanδ(w) is dissipation factor . The AC conductivity σ_{ac} Can be calculated by the following equation :

$$\sigma_{ac}(w) = \varepsilon_o w \varepsilon'' \qquad (4)$$

Results and Discussion

The observed variation of electrical conductivity of PMMA composites with increasing alumina content is illustrated in figure(1).The conductivity increases with increasing magnesium additive concentration.

Figure 1: Variation of D.C electrical conductivity with Al_2O_3wt% concentration for (PMMA-Al_2O_3) composite.



The increase of conductivity with increasing of concentration of alumina due to increases the charge carriers which increased with increasing filler contact where the alumina particles at a low concentrations are represented by small darker regions and become large when the alumina content increases and the network will be connected to each other containing the overlapping paths to allow the charge carriers to pass through, where the charge carriers with routes through which the electrical resistance be less[Bhattacharya *et.al* ,2008, He *et.al*,2005, Srivastava and Mehra,2009]. The source of the conductivity enhancement is the electrical contacts generated from the filler networks as illustrated in the microscopic photographs in figure (2) taken for samples of different concentrations.

Figure 2: Photomicrographs for PMMA- Al_2O_3 composite (a) for pure,(x50) . (b) for 25 wt.% Al_2O_3,(x50) (c) for 45 wt.% Al_2O_3,(x50)

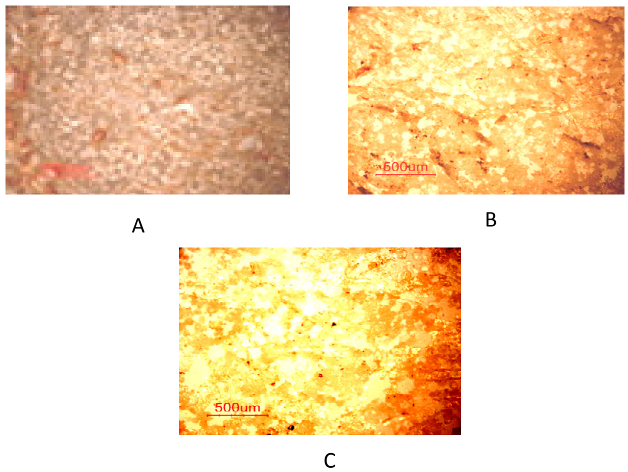


Figure (3) shows the behavior of electrical volume conductivity of the samples with the temperature. Note that the electrical conductivity increase with increasing temperature that any of this material has a negative thermal coefficient of resistance .the interpretation of this is that the polymeric chains and alumina particles act as traps the charge carriers which transited by hopping process. On increasing the temperature , segments of the polymer being to move , releasing the trapped charges . The released of trapped charges is intimately associated with molecular motion . The increase of current with temperature is attributed to two main parameters , charge carriers and mobility of these charges. The increase of temperature will increase the number of charge carriers exponentially. The mobility depends on the structure and the temperature [Al-Ramadhan,2008, Majdi and Fadhal,1997].

Figure 3: Variation of D.C electrical conductivity with temperatur for ($PMMA$-Al_2O_3) composite

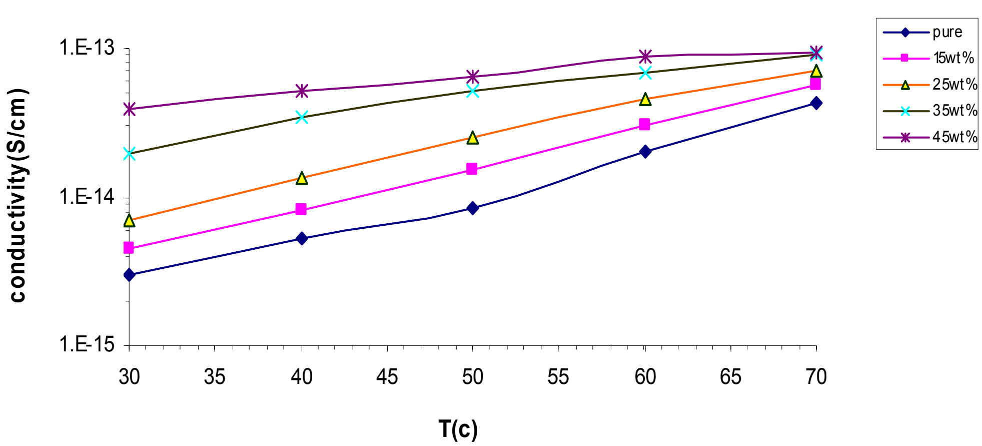
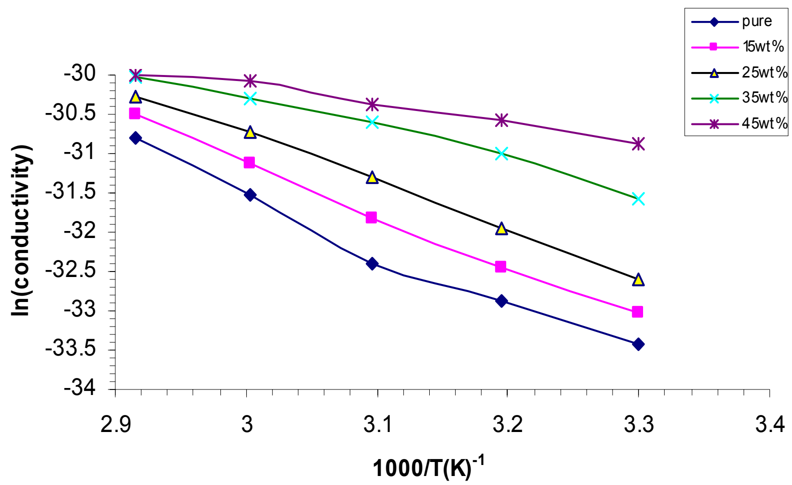


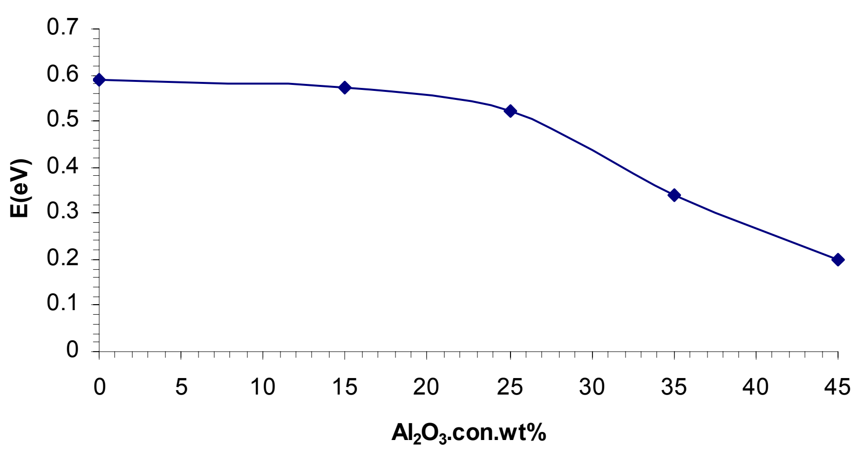
Figure (4) shows the relationship between the ln(conductivity) and inverted absolute temperature of the PMMA-Al_2O_3 composites, using equation $\sigma = \sigma_o \exp(-E_a/k_BT)$ was calculate activation energy, the high activation energy values for neat sample and low Al_2O_3 concentration sample can be attributed to the thermal movement of the ions and molecules, whereas the low activation energy values for the samples of higher Al_2O_3 content can be attributed to the electronic conduction mechanism which is related to the decreasing of the distance between the Al_2O_3 particles . [Hamzah *et.al* ,2008]

Figure 4: Variation of D.C electrical conductivity with resprocal absoute temperture for (PMMA-Al_2O_3) composite.



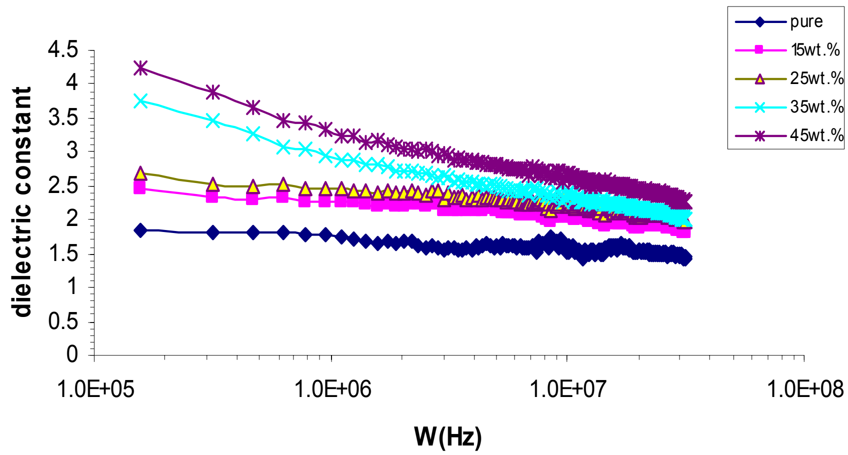
The concentration increasing of Al_2O_3 less the result of the activation energy as shown in the figure (5) of PMMA-Al_2O_3 composites which is a reasonable support for the above discussion [Ahmed and Zihilif,1992].

Figure 5: Variation activation energy for D.C electrical conductivity with Al_2O_3wt.% concentration for (PMMA-Al_2O_3) composite



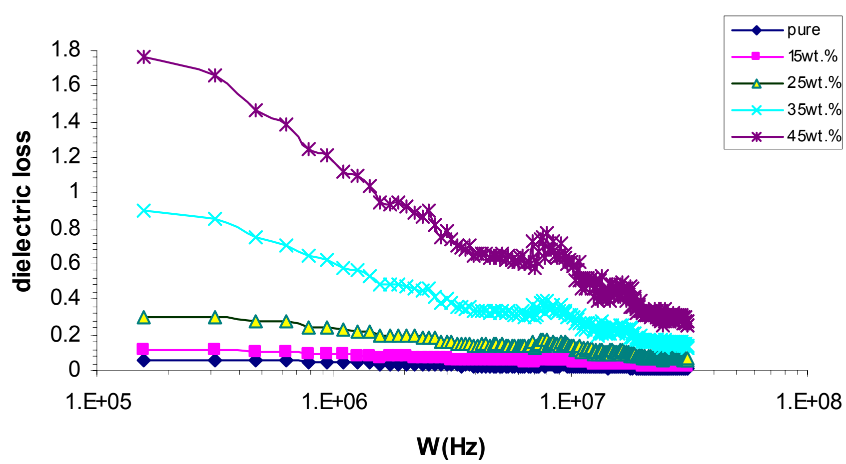
The variation of dielectric constant for PMMA-Al_2O_3 composites of different Aluminum concentration as function of frequency at room temperature is shown in figure (6). At low frequency region in addition to polarization due to PMMA and Al_2O_3, the space charge polarization plays a major role in increasing dielectric constant of composite[Hamzah *et al*, 2009]. The space charge polarization arises from the PMMA/Al_2O_3 interfaces. The dielectric constant increases with weight fraction of Al_2O_3. The increase in dielectric constant with weight fraction of Al_2O_3 supports the fact of the space charge polarization contribution. The dielectric constant of composite increases with addition of Al_2O_3 reflects the formation of capacitance network of Al. [Hamzah *et al*,2008].

Figure 6: Variation dielectric constant with angular frequency for (PMMA-Al_2O_3) composite.



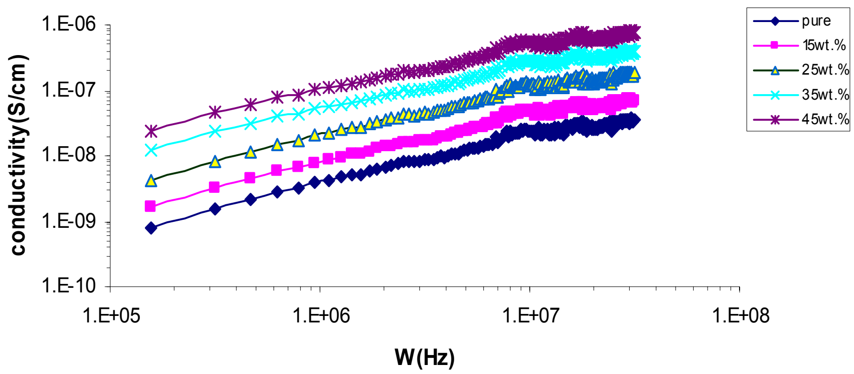
The variation of the dielectric loss of PMMA-Al_2O_3 composites as a function of frequency at room temperature is shown in figure (7) , the values of ε'' are high for frequencies, and decreasing with frequency and increases to reach maximum. The oscillatory behavior of ε'' may be due to some relaxation processes which usually occur in heterogeneous system. The relaxation peak at W=10MHz is appears clearly in all low Al_2O_3 concentration on specimens. The increasing of Al_2O_3 concentration increases the height of the peak and increasing its broadness for these specimens. This is due to the overlapping of relaxation process which are attributed to some structural changes that take place in the composite as result of filler addition . The increasing of the peak height of ε'' with increasing Al_2O_3 concentration indicates the enhancement of conductivity in these specimens , i.e. enhancement of losses [Raghavendra *et al*,2007, Pillal,1980] .

Figure 7: Variation of dielectric loss with frequency for (PMMA-Al_2O_3) composite.



The variation of A.C electrical conductivity as a function of frequency for (PMMA-Al_2O_3) composites at 303K is given in figure (8). The figure shows that in low, intermediate and higher frequency region the electrical conductivity for all (PMMA-Al_2O_3) composites is increasing with frequency. The increasing of A.C electrical conductivity with angular frequency in the low frequency region can be attributed to the interfacial polarization [Hamzah M.*et al*, 2009].

Figure 8: Variation of A.C electrical conductivity Frequency for (PMMA-Al_2O_3) composite.



The increasing of A.C electrical conductivity in high frequency region can be related to the electronic polarization as well as to the hopping of charge carrier over a small barrier height. The figure also indicates that $\sigma_{A.C}$ is increasing with increasing Al_2O_3 wt.% content, a result which supports the suggestion of hopping of charge carrier conduction mechanism [Hamzah M.*et al*,2008].

Conclusions

1. The D.C electrical conductivity of the poly-methyl methacrylate increases by increasing the Al_2O_3 concentrations and the temperature.
2. The activation energy of D.C electrical conductivity decreases by increasing alumina concentrations.
3. The dielectric constant decreasing with the frequency and increase with Al_2O_3 wt.% content .
4. The dielectric loss is oscillatory in the whole frequency region and increase with increasing Al_2O_3 wt.% content .
5. The A.C electrical conductivity of PMMA-Al_2O_3 composites is increasing with increasing frequency of applied electrical field and Al_2O_3 wt.% content .

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