

Conductivity Studies of PMMA/Al₂O₃ Composite

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Abstract— Poly methyl methacrylate (PMMA) / Al₂O₃ composites were prepared by sol gel method. The structural, micro structural and the dielectric properties of the composites were studied using X- ray diffraction (XRD), Scanning Electron Microscopy (SEM) and Hioki 3522-50 LCR Meter respectively. The electrical conductivity of composites has been investigated at different temperatures at frequency ranging from 50 Hz to 1MHz. The dielectric loss, dielectric constant and conductivity were changed with change in the concentration of Al₂O₃ and frequency of applied field. The electrical conductivities of the composites were found to increase with increasing temperature.

Keywords- PMMA, Al₂O₃, electrical conductivity, polymer composite

I. Introduction

Composites can be defined as materials that consist of two or more chemically and physically different phases separated by a distinct interface. Composites, the wonder materials are becoming an essential part of today's materials due to the advantages such as low weight, corrosion resistance, high fatigue strength, and faster assembly. They are extensively used as materials in making aircraft structures, electronic packaging to medical equipment, and space vehicle to home building. Composite materials having long-term durability for continuous purposes are desirable and cost-effective. There is much interest in the development of inexpensive composite polymers with an appropriate weight, appropriate electric conductivity and/or appropriate impact value for use with practical articles Itoh et al (2006a), Itoh et al (2006b), Kanda et al (2009). Polymer composites have steadily gained growing importance during the past decade. 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 Kryzewski (1975). 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 field Mead (1961). A good amount of work has been reported on the conduction mechanism in polymeric materials. The electrical conduction in polymer film has much importance due to the discovery of the memory phenomenon and has wide applications now-a-days in thin film devices Chakraborty et al (1991). The electrical conduction in iodine doped polystyrene (PS) and poly(methyl methacrylate) (PMMA) has already been reported Sangawar et al (1995). Belsare et al (1998) measured the electrical conductivity of iodine doped polyblend films of polystyrene (PS) and poly(methyl methacrylate) (PMMA). Electrical conduction in semiconducting PVC-PMMA thin film has been reported Deshmuk et al (2005).

II. EXPERIMENTAL

A. Chemicals and reagents

The monomer MMA, Al₂O₃, benzoyl peroxide, chloroform and petroleum ether were obtained from Alfa Aesar, India and used as such.

B. Preparation of PMMA

The purified monomer (MMA) (10ml) was taken in a polymerization tube and 50mg of benzoyl peroxide which acts as a catalyst was added to accelerate polymerization, in the polymerization reaction. The polymerization tube was then kept in a water bath at 60-70°C with periodical shaking. A hard viscous polymer was obtained after 90 minutes of heat treatment. The polymerized mass was dissolved in chloroform and then transferred into a beaker. The viscous polymer solution was precipitated by the addition of petroleum ether. The precipitated polymer was then filtered and oven dried at 60°C. The polymer formed was found to be syndiotactic devikala et al (2011).

C. Preparation of PMAl composites

A definite quantity of PMMA was dissolved in chloroform followed by the addition of a known quantity of Al₂O₃ and then it was made into a paste in an agate mortar then it was subjected to heat at 80°C for 1 hour in a Muffle furnace and made into a powder. PMAl composites were prepared in the following

proportions of PMMA and Al_2O_3 : PMA1 1 – 9:1, PMA1 2 – 8:2, PMA1 3 - 7:3, PMA1 4 -6:4, , PMA1 5 – 5:5 and PMA1 6 – 4:6.

D. PXRD

In order to understand the properties of composite material, it is essential to know about the details of its structure. The X-ray diffraction pattern (XRD) technique was used for characterization. The PXRD of PMMA, Al_2O_3 and PMA1 composites were recorded using Philips X'PERT PRO diffractometer with Cu K ($\lambda = 1.54060 \text{ \AA}$) incident radiation. The XRD peaks were recorded in the 2θ range of 20° – 80° .

E. SEM

The Scanning electron microscopy produces detailed photographs that provide important information about the surface structure. The morphology of PMMA, Al_2O_3 and PMA1 composites are recorded using Philips XL30. The samples were gold plated before SEM observation.

F. Dielectric properties and conductivity measurement

The electrical conductivity of composites were measured using Hioki 3522-50 LCR Meter. Testing temperature ranged from 40 to 60°C at frequency ranging from 50 Hz to 1 MHz .

III. RESULTS AND DISCUSSION

A. PXRD

Pure PMMA showed a predominant and broad peak with a maximum at $2\theta = 13.89^\circ$ along with broad but low-intensity peaks at 30° and 34° . These broad peaks indicated the amorphous nature of the polymer (Fig.1). XRD of pure Al_2O_3 is shown in the figure 20. Peaks at $37.88(110)$, $42.41(113)$ and $67.09^\circ(214)$ correspond to the diffraction patterns of Al_2O_3 respectively. After the formation of the composite PMA1, the peaks were suppressed and a broad peaks appeared at 14° and 15° with a maximum at 15.04° . This indicate an increase in the amorphous nature of composites. Thus the addition of Al_2O_3 to PMMA may induce a significant increase in the amorphicity of composite materials.

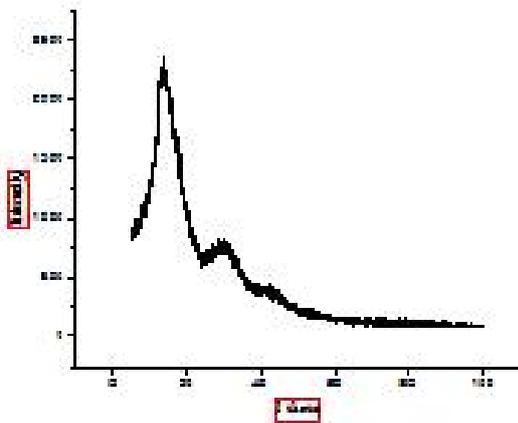


Fig. 1. XRD of PMMA

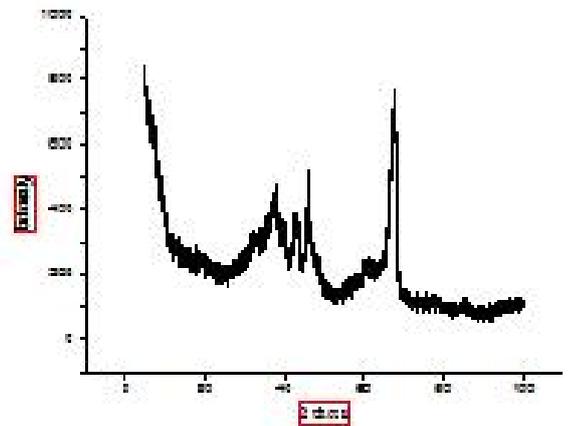


Fig. 2. XRD of Al_2O_3

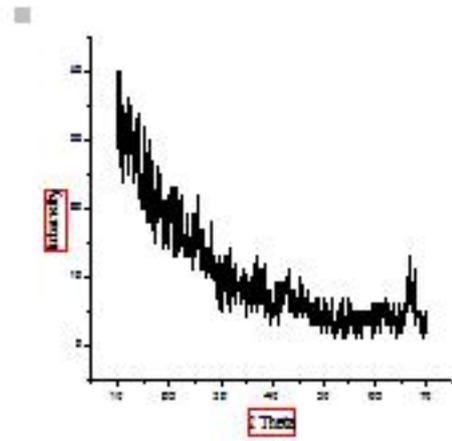


Fig. 3. XRD of PMAI₆

B. SEM

The SEM images of PMMA, Al₂O₃ and the composite, PMAI 6 were shown in the figures 4,5 and 6 respectively. The composite possess smooth surface when compared to PMMA. The rough fractured surface of PMMA was changed due to the addition of Al₂O₃.

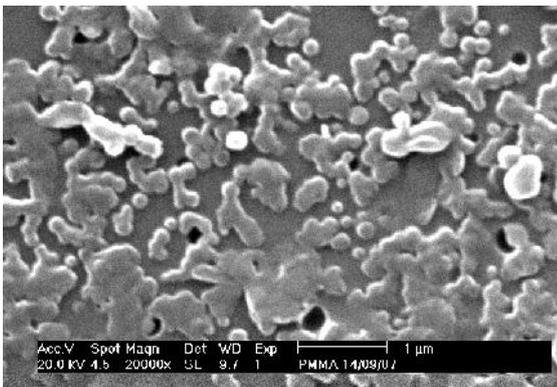


Fig. 4. SEM image of PMMA

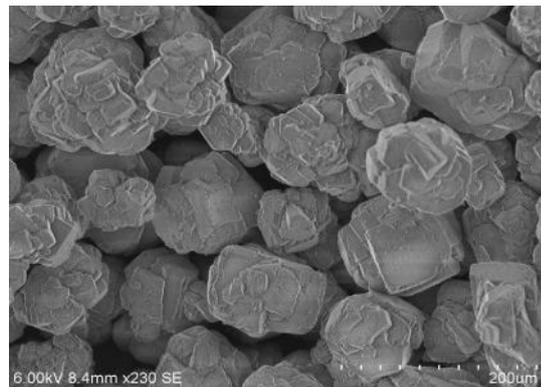


Fig. 5. SEM image of Al₂O₃

The micrograph of pure PMMA shows a homogenous phase. SEM showed how the PMMA microspheres are inserted in the fine-grained solid-organic matrix. However, the PMMA contraction was found favourable, since this non-rigid behavior avoided the formation of cracks due to the absence of tensile stresses in the matrix. No density gradients of templates were observed in the cross sections analysed by sem, showing in all cases a homogenous microstructure. The inorganic moieties were well dispersed in the PMMA matrices. From the above observations it can be concluded that in our composite systems there was a good compatibility between the organic and inorganic components and the micro metred sized inorganic particles are well dispersed in the PMMA matrix.

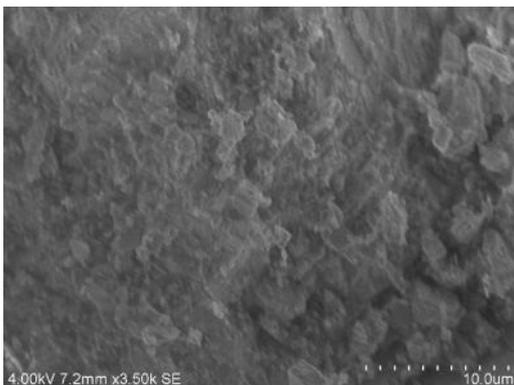


Fig. 6. SEM image of PMAI₆

B. AC conductivity of PMMA/ Al₂O₃ composites

The measured conductance G, from 50 Hz to 5000000Hz used to calculate ac conductivity, (σ_{ac}) using the following expression:

$$\sigma_{ac} = G d/A$$

where d is the thickness of the sample and A is the cross sectional area of the electrode. The AC conductivity of PMAI composites at different temperatures were shown in Table 1. Polymer materials in pure state are electrical insulators. However they are filled with specific additives, as metallic powders metallic fibers, ionic conductive polymers, etc. The conductivity of pure PMMA was found to be 5×10^{-18} S/cm. El-Bashir et al (2010). The electrical conductivity of the composite increased with the Al₂O₃ content. The electrical conductivity of the composites exhibited a pronounced transition with the increase of Al₂O₃ content, from an insulator to nearly a semiconductor. The increase of ac conductivity can be related to the electronic polarization as well as to the hopping of charge carrier over a small barrier height. The Table 1 indicates that ac conductivity is increased with increasing alumina content, a result which supports the suggestion of hopping charge carrier conduction mechanism This transition can be satisfactorily explained and described by the formation of the conductive network in the composite Pan et al (2000). As the temperature increased, the charge carries are thermally activated and the free volume increases and more vacant sites are created for the motion of ions, which in turn enhanced the conductivity.

Table 1. shows the variation of conductivity with Al₂O₃ concentration for different temperatures.

System studied	Conductivity (S/cm)		
	313K	323K	333K
PMAI 1	1.48×10^{-9}	1.95×10^{-8}	1.56×10^{-7}
PMAI 2	2.75×10^{-9}	2.37×10^{-8}	2.56×10^{-7}
PMAI 3	3.01×10^{-9}	3.89×10^{-8}	3.89×10^{-7}
PMAI 4	4.41×10^{-9}	4.92×10^{-8}	4.90×10^{-7}
PMAI 5	5.95×10^{-9}	5.96×10^{-8}	5.75×10^{-7}
PMAI 6	6.68×10^{-9}	6.80×10^{-8}	6.71×10^{-7}

C. Dielectric properties

The higher value of dielectric constant is due to higher grain size. The dielectric constant strongly depends on the grain size. The dielectric constant of materials was due to the electronic, ionic, dipolar and surface charge polarizations which depend on the frequencies. The larger value of dielectric constant at lower frequency may be due to space charge polarization arising at the grain boundary interfaces. Figures 7 and 8 showed the variation of dielectric loss and dielectric constant as functions of frequency. In both the plots, the dielectric loss and dielectric constant decreased with the increase of frequency, which was in good agreement with the reported value Fang et al (2006).

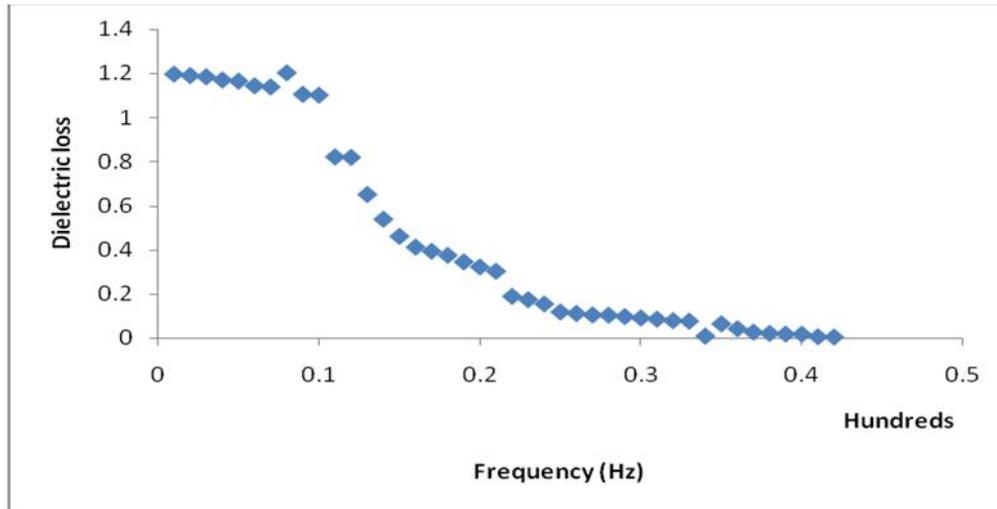


Fig. 7. Variation of dielectric loss with frequency at 333K for PMAI 6

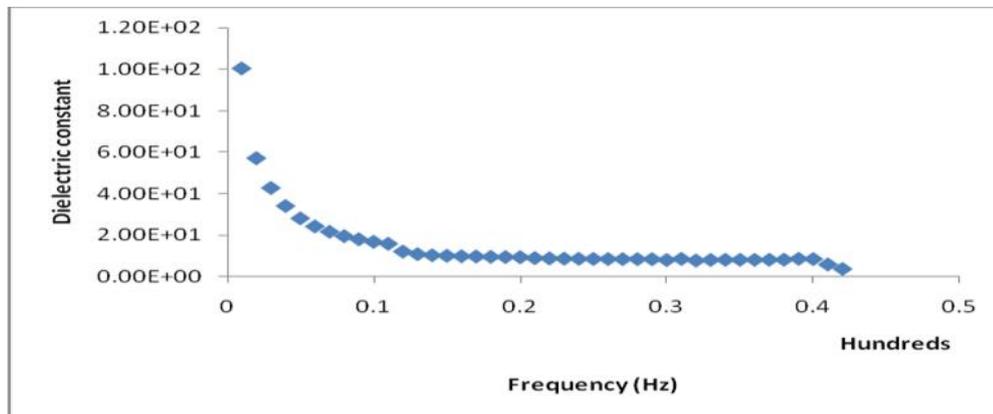


Fig. 8. Variation of dielectric constant with frequency at 333K for PMAI 6

IV. CONCLUSION

Poly methyl methacrylate (PMMA) / Al_2O_3 composites were prepared by sol gel method. The polymer composites were characterized using PXRD and SEM. The electrical conductivity and dielectric properties of the polymer composites were measured. The A.C electrical conductivity of the composites increases by increasing the Al_2O_3 concentrations and with increased temperature. As the temperature increasef the charge carries were thermally activated and the free volume increases and more vacant sites are created for the motion of ions, which in turn enhances the conductivity. The dielectric loss and dielectric constant decreased with the increase of frequency. This was due to the electronic, ionic, dipolar and surface charge polarizations which depend on the frequencies. The large value of dielectric constant at lower frequency may be due to space charge polarization arising at the grain boundary interfaces.

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