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Electrical and thermal conductivity of polyvinylidene fluoride (PVDF) – Conducting Carbon Black (CCB) composites: Validation of various theoretical models

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ABSTRACT

Different composition dependent PVDF/CCB composites were prepared by solution mixing followed by casting technique. The morphology, crystallinity, electrical and thermal conductivity, sound velocity and storage modulus vary with composition. The effect of frequency, temperature and composition on electrical conductivity were investigated and electrical conductivity of these composites strongly depends on percolation threshold. The variation of thermal conductivity and storage modulus against temperature and concentration has also been investigated. The surface morphology has been viewed through Field Emission Scanning Electron Microscopy (FESEM) and Atomic Force Spectroscopy (AFM). The particle agglomerate structure of CCB was checked byHigh Resonance Transmission Electron Microscopy (HRTEM). Applicability of different theoretical models to predict electrical conductivity and thermal conductivity were also tested for these composites. To predict composition dependent thermal conductivity theoretical models like Series, Parallel, Geometrical mean, Maxwell, Nielsen Lewis, Hamilton-Crosser, and the Agari model have been used to check their validity for the present system.

1. Introduction

Polymers in general are insulating in nature and often used as thermal and electrical insulant for electrical equipment and heating devices. This is because the electrical and thermal conductivity of polymers are significantly low. However, incorporation of suitable conductive additive in appropriate concentration can convert an insulating neat polymer into conductive polymer composites. In fact, polymer composites with conductive additives like metal and carbon particles can show remarkable conductive properties and were widely explored during last decade [1–6]. These conducting polymer composites are suitable for different applications. Recent investigations revealed that these conducting polymer composites can be used for shielding of electromagnetic/radio frequency interference in electronic devices and antistatic materials mainly because of their better performance compared to conventional materials [1–4,7,8]. Several theoretical models have been proposed to predict the thermal and electrical conductivity of the two phase composite systems (polymer-filler). But such models are not universally applicable to all polymer-filler systems [9–15]. The conductivity of polymer-filler biphasic systems depends on different aspects of constituents of the composite for example filler concentration and conductivity, its geometrical aspects (aspect ratio), its distribution and dispersion in matrix polymer as well as properties of insulating matrix like its conductivity, viscosity and surface tension. Thus it was not possible to take care of all these variables in single modeling proposed so far.

Polymers have low thermal conductivity due to their covalent bonds and complex molecular structure which does not have long range electron movement, coupled with low atomic density and high anharmonicity in their molecular vibrations. The thermal conductivity and heat dissipation efficiency can be improved by modifying their crystalline structure [16]. It has been reported that the addition of fillers like carbon fiber, carbon nanotube, graphite, carbon black, metal particles, ceramic powder etc. enhances the thermal and electrical conductivity of polymer matrix remarkably [13–15,17]. The incorporation of conducting filler also protects the composite from overheating by improving effective heat dissipation.

The dissipation of heat is very essential in microelectronic packaging material used in designing of many new products [18]. The materials that are generally used as a sink for heat from encapsulated devices has

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