Research Article

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Electrical conductivity and dynamic mechanical properties of silicon rubber-based conducting composites: effect of cyclic deformation, pressure and temperature

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Abstract

The effects of cyclic deformations such as bending and compressive flexing, temperature and pressure on electrical and dynamic mechanical properties of conductive polydimethylsiloxane (PDMS) composites have been investigated. Conductive elastomeric composites were prepared by incorporating various carbon blacks in insulating PDMS matrix. Electrical conductivity was measured against varying concentration of different carbon blacks to assess the percolation threshold of the composites. AC and DC conductivity was found to increase with an increase in some bending flex cycles. However, with compressive flexing, DC conductivity initially dropped but later started increasing with an increase in flex cycles. The variations in electrical conductivity and dynamic mechanical modulus due to bend flexing are found to be similar, i.e. both characteristics show an increase in magnitude with an increase in some flex cycles. DC resistivity was found to increase with heating–cooling cycles, and this change in resistivity did not follow the same path leading to electrical set and hysteresis.
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Keywords: carbon black; conductive network; flex cycle; frequency

INTRODUCTION

Polymers are traditionally known as insulators because of the intrinsic properties of covalent bonds, which constitute almost all of the bonding in polymers.[1] Because of this, polymers are neither capable of providing free electrons for electrical conduction nor able to serve as a path for carrier movement. Thus, they are regarded as electrically non-conducting and have been accordingly used as such in applications. But with the technological revolution, the need for electrically conducting polymers has gained significant importance due to their various applications such as electromagnetic interference shielding materials, static electric charge dissipation, spark proof rubber contact switches, pressure-sensitive sensors and semiconducting materials in high-voltage cables and circuit components in microelectronics.[2–5] Consequently, the preparation of conducting polymers and modification of their electrical performance have gained significant importance.

The modification of electrical conductivity of polymers can be done in two ways. The first way is to chemically synthesize inherently conducting polymers, but these lack good mechanical and processing properties. The second and rather easier way of developing electrically conductive polymeric materials is through the incorporation of various conductive additives in the form of powders, flakes or fibres into a polymer matrix.[1,6–10] This method allows composite materials to be prepared with electrical properties close to those of the conductive additives coupled with good mechanical and processing properties. Among various types of conductive additives, carbon black is the most widely used for rubber matrices as it is cheap, easily processed and also offers good reinforcement to the rubber matrix.[11–13] The electrical conductivity of rubber composites is largely influenced by the type and amount of carbon black in addition to its degree of dispersion within the rubber matrix and filler–matrix interfacial effects.[14–16] Carbon black of smaller particle size and high structure imparts higher conductivity to a polymer matrix.[17,18] Some other factors such as temperature, pressure, degree of carbon black loading and extent of crosslinking have a profound influence on the overall conductivity of rubber composites.[19,20]

When such conducting elastomeric composites are subjected to dynamic applications, they are exposed to a variety mechanical deformations and temperature and pressure variations. Thus, it becomes necessary to understand the specific changes in their electrical and dynamic mechanical properties as a function of mechanical deformation. The electrical characteristics of conductive composites are related to concentration, size and shape of the conductive filler particles and also to possible interactions between the conductive and the insulating phases. Though some works are available on the electrical properties of polydimethylsiloxane (PDMS) and conducting carbon black-filled composites,[21,22] the effect of various cyclic deformations, temperature and pressure on electrical and dynamic mechanical properties of conducting PDMS composites have not been investigated in detail.

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Determination of percolation threshold and electrical conductivity of polyvinylidene fluoride (PVDF)/short carbon fiber (SCF) composites: effect of SCF aspect ratio

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Abstract

Composites of polyvinylidene fluoride (PVDF) and short carbon fibers (SCFs) with different aspect ratios of the SCFs were prepared by the solution casting technique. The electrical percolation thresholds of the composites are highly influenced by the SCF aspect ratio calculated using both the Sigmoidal Boltzmann model and classical percolation theory. It was observed that the percolation threshold of PVDF/SCF composites decreases with an increase in the aspect ratio of the SCFs in the PVDF matrix. Different theoretical models were used to check the alignment of the SCFs in the PVDF matrix. The applicability of the theoretical models was tested to predict the composition-dependent electrical conductivity at different SCF loadings and aspect ratios and the predictions were compared with experimental results. The effect of the fiber aspect ratio on the AC electrical conductivity was also investigated. Finally, the transparency of the composites was tested with the help of UV–visible spectroscopy and exhibits an SCF loading dependence in the PVDF matrix.

Keywords: polymer composite; aspect ratio; percolation threshold; conductivity; filler loading; short carbon fiber

INTRODUCTION

Polyvinylidene fluoride (PVDF) is a well-known piezoelectric polymer. Flexible and transparent conductive composites of PVDF can be used in various applications such as actuators, high charge storage capacitors, sensors, audio devices, electromagnetic interference shielding for electronic devices, artificial muscles, micro-electromechanical systems and electrostatic dissipation.[1−7] PVDF has the unique property of making its composites resistant to corrosion, with good melt processability, low gas permeability, high mechanical strength and creep resistance at elevated temperature.[8−10] Ceramic loaded polymer composites are high dielectric materials, but the ceramic reduces flexibility.[1] It has been mentioned in the literature that a large quantity of carbon black is needed (which causes opacity) to get a similar range of electrical percolation thresholds compared to carbon nanotube, carbon nanofiber and carbon fiber filled composites.[11−15] Transparency of the polymer composite can be achieved through carbon fillers that have less interparticle interaction and low percolation loading in the polymer.

Extrinsic conductive polymer composites are often prepared by the addition of an adequate amount of conducting fillers in insulating polymer matrices.[16] Carbon fillers (such as carbon fiber, carbon nanofiber, graphite, carbon nanotube, graphene, carbon black etc.) are an example of conducting fillers through which the electrical conductivity of polymers can be enhanced up to a certain level.[17−23] The percentage of carbon in carbon fiber and graphite fiber is 92 wt% and 99 wt%, respectively.[24] Carbon fiber has high thermal and electrical conductivities, high thermal and chemical stabilities (in the absence of oxidizing agents), low density and excellent tensile properties. The properties of the fibers (carbon/graphite) are affected by many factors such as crystalline distribution, molecular orientation, crystallinity, the number of defects and carbon content.[25] The aspect ratio (the ratio of length to diameter) of the conductive fillers greatly influences the performance of the polymer composites.[26−28]

The aim of this research was to investigate the effect of the aspect ratio of short carbon fibers (SCFs) on the DC and AC electrical conductivity and the dependence of the transparency on the SCF loading in the PVDF matrix. The PVDF/SCF composites were prepared by the solution casting method in which SCFs were randomly oriented in the PVDF matrix. The Sigmoidal Boltzmann model and classical percolation theory were used to correlate the DC conductivity percolation threshold. Different conductivity models were tested to check their applicability for the present

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Analysis of Electrical and Dynamic Mechanical Response of Conductive Elastomeric Composites Subjected to Cyclic Deformations and Temperature

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Effects of different mechanical deformations such as cyclic bending and compressive flexing and temperature on electrical and dynamic mechanical properties of elastomeric composites have been investigated. Conductive elastomeric composites were prepared by incorporating different carbon blacks in an insulating polychloroprene (CR) rubber matrix. The filler loading was varied between 10 and 110 phr (parts per hundred rubber) i/r/o different carbon blacks to assess the percolation threshold of different composites. Due to the spatial arrangement of conductive filler particles at certain critical concentration, some conducting networks are formed leading to abrupt increase in conductivity of polymer composites. This critical concentration is known as percolation threshold. The increase in conductivity well below and above percolation threshold is relatively less compared to that around percolation. The variation of electrical conductivity and dynamic mechanical modulus due to bending and compressive flexing are found to be similar, that is, both characteristics show a drop in magnitude with increase in number of flex cycles. The conductivity of system changes when composites are subjected to changes in temperature. This is mainly due to the destruction of existing conducting networks as well as formation of some new conducting networks. The net change depends on the degree of formation or destruction of networks. It is interesting to see that conductivity does not follow the same path during heating–cooling cycles thereby causing electrical hysteresis. POLYM. COMPOS., 39:3912–3923, 2018. © 2017 Society of Plastics Engineers

INTRODUCTION

Polymers, in general, behave like insulators because the atoms in polymer chains are covalent bonded [1]. Due to this, polymers are neither able to conduct charge themselves and nor able to serve as a path for carrier movement. Thus, they are regarded as electrically non-conducting and have been accordingly used in such applications. But with technological revolution, the need for electrically conducting polymers has gained a significant importance due to their various applications such as electromagnetic interference shielding materials, static electric charge dissipation, rubber contact switches, pressure sensitive sensors and semi-conducting materials in high voltage cables and circuit components in microelectronics [2–7]. Consequently, over a period of time, the preparation of conducting polymer and modification of their electrical performance has gained a significant importance.

The electrically conducting rubber composites are usually prepared by dispersing conducting fillers like carbon black, carbon fibre, carbon nanotube, graphene, coke, metal oxides (like alumina, mica) and non-oxidizing metal powders (such as silver, nickel) in the rubber matrix [8–11]. Among different types of conductive additives, carbon black is the most widely used for rubber matrix as it is less expensive, easily processed and also offers good reinforcement to the rubber matrix [12–14]. The electrical conductivity of rubber composites is largely influenced by the type and amount of carbon black in addition to its degree of dispersion within the rubber matrix and filler-matrix interfacial effects [15–18]. Carbon black of smaller particle size and high structure imparts higher conductivity to the polymer matrix [19–22]. A number of other factors such as temperature, pressure, the degree of black loading and the extent of cross-linking have a profound influence on the overall conductivity of rubber composites [23–25].

The elastomeric composites are suitable for dynamic applications. When these conducting elastomeric composites are subjected to dynamic applications, they get exposed to different types of fatigues and temperature. Thus, it becomes important to understand changes in their electrical and dynamic mechanical characteristics with cyclic deformations. Their electrical characteristics are related to the concentration, size, and shape of the particles and also to possible interactions between the conductive and the insulating phases. Though some works are available on electrical properties of CR and conducting carbon black filled composites [26–28], the effect of cyclic deformations and temperature on electrical and dynamic mechanical

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