Graphite-high density polyethylene laminated composites with high thermal conductivity made by filament winding

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Abstract. The low thermal conductivity of polymers limits their use in numerous applications, where heat transfer is important. The two primary approaches to overcome this limitation, are to mix in other materials with high thermal conductivity, or mechanically stretch the polymers to increase their intrinsic thermal conductivity. Progress along both of these pathways has been stifled by issues associated with thermal interface resistance and manufacturing scalability respectively. Here, we report a novel polymer composite architecture that is enabled by employing typical composites manufacturing method such as filament winding with the twist that the polymer is in fiber form and the filler in form of sheets. The resulting novel architecture enables accession of the idealized effective medium composite behavior as it minimizes the interfacial resistance. The process results in neat polymer and 50 vol% graphite/polymer plates with thermal conductivity of 42 $W \cdot m^{-1} \cdot K^{-1}$ (similar to steel) and 130 $W \cdot m^{-1} \cdot K^{-1}$ respectively.

1. Introduction

Recently, there has been huge interest to use polymers as heat conductors, in applications where heat transfer is important. These applications range from potentially using polymers in heat exchangers to heat spreading and electrically insulating flexible substrates for electronic components, such as LEDs. The problem is that as polymers are typically amorphous in nature [1] they have low thermal conductivity, typically on the order of 0.1 $W \cdot m^{-1} \cdot K^{-1}$. The two primary approaches pursued to increase the thermal conductivity of the polymers are: 1) adding high thermal conductivity materials to polymer matrices to form composites [2–4] and 2) mechanically stretching the native polymer itself to increase its own thermal conductivity [5–11].

With regards to the addition of high thermal conductivity filler materials to form composites, the concept is based on the idea of effective medium theory [12, 13]. A simple rule of mixtures argument would suggest that the thermal conductivity of a composite should be simply determined by the polymer thermal conductivity $\kappa_{polymer}$ the filler material's thermal conductivity κ_{filler} and the respective fractions of each phase by volume where, ϕ is the filler's fraction, via Equation (1):

$$\kappa = \kappa_{polymer}(1 - \phi) + \kappa_{filler}\phi \qquad (1)$$

This is the simplest model one can employ for a multiphase system [12, 13]. Given that there are many low cost filler materials with high thermal conductivity (e. g., on the order of 10–1,000 $W \cdot m^{-1} \cdot K^{-1}$) [14–18] that is at least two orders of magnitude higher than that of amorphous polymers, a body of research has been devoted to homogeneously disperse filler materials into polymer matrices [1, 4, 18–20]. The problem,

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