



Measurement and modelling of the thermal conductivity of dispersed aluminium composites[☆]

James K. Carson

School of Engineering, University of Waikato, Private Bag 3105, Hamilton 3240, New Zealand

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ABSTRACT

Measurements of the thermal conductivity of a model system (squat aluminium cylinders suspended in an aqueous carbohydrate polymer gel) have been performed for a range of compositions up to the packing factor limit of the aluminium (approximately 0.6). Of a variety of models considered, the Cheng–Vachon model provided the most accurate predictions of thermal conductivity, and it was argued that this would also be the case for suspensions of most metals in polymer matrices. A modified form of the Cheng–Vachon model was used to obtain an even closer fit to the experimental data.

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1. Introduction

Metal-powder/polymer composites are a useful class of material because their physical properties may, within limits, be selected to match the requirements of a particular application [1–9]. In particular there is interest in enhancing mechanical and/or thermal properties, whilst retaining the low weight, mould-ability and formability (at relatively low temperatures) of the polymer. Ideally manufacturers would be able to calculate in advance the required composition of a composite in order to produce its desired properties. In order for this to be achieved it is important to be able to model the physical properties as a function of composition accurately.

The author has previously investigated the thermal conductivity and thermal diffusivity dependence of aluminium/polyethylene composites which were prepared using a twin-screw extruder which blended the polymer and metal at an average temperature of 170 °C [8]. Whilst this method of producing the composites was effective and relatively simple, there was a limit to the amount of aluminium powder that could be added to the polyethylene due to the limits in ‘extrude-ability’ imposed by the equipment. As a result the volume fraction of the aluminium within the composite was less than 0.2; preferably, for the purposes of model validation, data would be available over a range of volume fractions at least up to 0.5. This paper reports measurements of thermal conductivity for an aluminium/aqueous gel system (which is thermally analogous to the aluminium/polyethylene system described in Ref. [8]) for volume fractions of aluminium up to 0.603. Selected thermal

conductivity models from the literature were also compared to the measured data.

2. Methods and materials

The thermal conductivity measurement was achieved using a transient-comparative method that has been described in detail previously [10,11]. Briefly, a spherical sample of the material is cooled (or heated) in a water bath alongside a reference material whose thermal properties are known. The thermal conductivity of the sample can be determined from Eq. (1)[10]:

$$k_e = k_{ref} \frac{\sigma_e \rho_e c_e}{\sigma_{ref} \rho_{ref} c_{ref}} \frac{R_e^2}{R_{ref}^2} \frac{\lambda_{ref}^2}{\lambda_e^2} \quad (1)$$

Note that the latter two ratios on the right hand side of Eq. (1) should be close to unity, provided the test sample and reference containers are the same size and the Biot number is sufficiently high [8,10].

The experimental samples in this study were comprised of squat aluminium cylinders (5 mm diameter, 5 mm height) suspended in a carbohydrate polymer gel (guar gum). The gel had almost identical thermal properties to water (since it was 96% water by mass), which are also comparable to the thermal properties of polyethylene [8]. The gel was used so that the aluminium cylinders could be suspended, and hence be distributed with spatial uniformity throughout the sample. The sample preparation was a skill acquired only after much practise as there was a limited window during which time the gel had thickened sufficiently that the cylinders would not sink, but had not yet set fully, allowing for dispersal of the cylinders. Each sample was visually inspected at the completion of a measurement run to assess the uniformity of the distribution of the aluminium cylinders; where

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E-mail address: j.carson@waikato.ac.nz.