Thermal Properties Of Composites - Measurements, Models and Thermal Exposure Derived Changes in MMCs and CMCs

Summary:

Thermal properties of composites can vary with thermomechanical service as a result of changes to the interface between matrix and reinforcement. This Measurement Note reports the results of an evaluation, undertaken with DTI project DCC2, of the potential of thermal property models to predict and quantify any changes. It assesses whether microstructural alterations, such as interphase reactions or delaminations, will induce significant and measurable changes to thermal properties. It is shown that, generally, models fall into two clases:

- insensitive to microstructural detail (specific heat and thermal expansion behaviour);
- sensitive to microstructural detail (thermal conductivity and thermal diffusivity, especially when the thermal conductivity of the reinforcement is high compared with that of the matrix).

For many types of composite this offers the opportunity of using thermal conductivity obtained non-destructively as a means of detecting interfacial changes.

Rationale:

There has been extensive research into modelling the thermal property characteristics of composite materials of all types, but the match to practical measurements is frequently not that good. This is attributed to the assumptions made in creating models, which are often somewhat simplistic, and assume simple geometrical arrangements and specific interface conditions between matrix and reinforcement. In practice, the condition of interfaces may not be known, or may change with use conditions, e.g. in mechanical or thermal cycling. The purpose of the present review is to examine available models and the assumptions behind so that the sensitivity of thermal properties to structural changes is understood, and hence whether there are prospects of using thermal property measurements as a non-destructive tool for evaluating a composite's condition in service.

The Review:

The predicted behaviour of composites from thermal property models was examined with special regard to the assumptions in models associated with interface conditions, and hence how sensitive the behaviour of the composite would be to changes in the interface condition. The review also covered thermal expansion, thermal conductivity/ thermal diffusivity and specific heat measurement methods, the accuracies of measurement, and the possibilities for non-destructive techniques for application to components rather than prepared test-pieces.

Examination of published models for **thermal expansion** behaviour reveals them to be complex and the results sensitive to thermoelastic parameters which sometimes are not readily measured, such as the transverse thermal expansion and elastic properties of fibres in fibre-reinforced metals (FRM) and ceramics (CMC). While some progress has been made in modelling hysteresis effects in thermal cycling, and models exist for evaluating changes in interface characteristics, sensitive thermal expansion measurement is normally restricted to prepared test-pieces, rather than components. The distinction between real changes and hysteresis may be difficult to determine accurately.

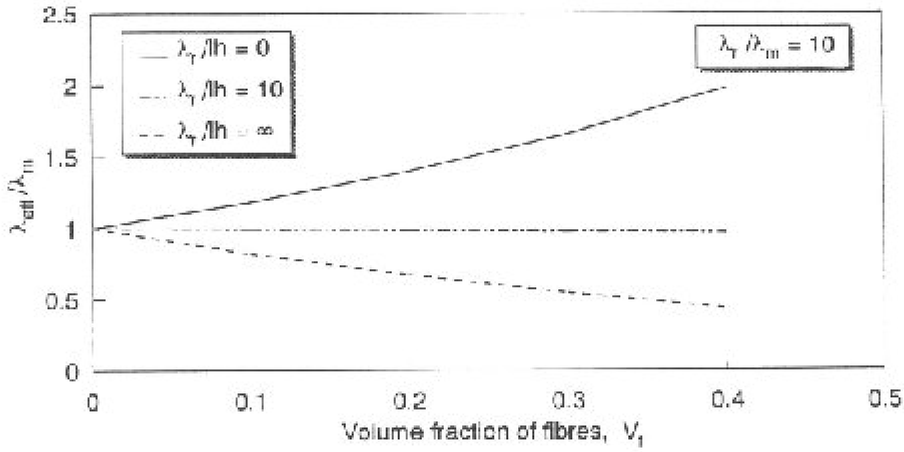

Figure 1: Ratio of transverse composite to matrix thermal conductivity ($\lambda_{eff} / \lambda_m$) as a function of fibre volume fraction predicted for various values of the non-dimensional parameter λ_r / lh where λ_r is the transverse fibre conductivity, *h* is the heat transfer coefficient between matrix and reinforcement, and *l* is a characteristic dimension, in this case the radius of the fibre.

Thermal conductivity models are generally less complex than those for thermal expansion. With high-conductivity reinforcement, the thermal conductivity of particulate-reinforced composites and the transverse thermal conductivity of fibre or whisker-reinforced composites become very sensitive to interface conditions (Figure 1). As far as test methods are concerned, there are possibilities for using probe-type methods for nondestructive measurement, enabling components to be routinely examined.

Thermal conductivity or thermal diffusivity measurements therefore offer a real possibility for monitoring structural changes during service.

While **specific heat** is known to change in the presence of internal stress or when new phases are formed at interfaces, the magnitude of these changes is rather small. In addition, specific heat measurement techniques which are sufficiently sensitive to detect such changes require small, carefully prepared test-pieces, and thus do not offer real possibilities as a non-destructive tool.

Acknowledgements:

This work was performed as part of "Design with Composite Components Project 2" supported by the Department of Trade and Industry under the "Materials Measurement Programme".

Report:

The review, which contains theoretical models and experimental results, is available on request as an NPL external report no. CMMT (A) 6.

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ISSN 1366-4506

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CMMT(MN)010

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1997