

Evaluation of transverse thermal diffusivity of unidirectional fiber-reinforced composites

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Abstract—The applicability of the homogeneous medium approximation to transverse transient heat conduction in unidirectional fiber-reinforced composites is examined. The study focuses on the problem of transient heat conduction in thin cross-sections, encountered in applications such as the manufacture of commercial prepreg tapes, the filament winding process, etc. The flash experiment for measuring the apparent transient diffusivity was numerically simulated for a wide range of composite parameters. Based on the parametric studies, a critical sample thickness is proposed, above which the composite may be analyzed in a simplified manner as a homogeneous medium having an equivalent transient thermal diffusivity. Below the critical thickness, the homogeneous medium approximation may introduce non-negligible errors. An analytical means for the evaluation of the homogenized transient diffusivity in practical situations is also presented.

INTRODUCTION

THE STEADY state thermal conductivity and the transient thermal diffusivity are important parameters involved in the manufacture of composite materials, and in their design for various high temperature applications. During the analysis of composite materials, it is desirable to approximate the heterogeneous material as a homogeneous medium having 'effective' properties, since this allows for substantial simplification of the process simulations. This approximation, referred to as homogenization of the composite material, is well established and widely accepted in the case of steady state heat conduction in composite media. The literature abounds with studies on the steady state heat conduction in composite materials, aimed at obtaining the 'effective' thermal conductivity, k_c , as a function of the composite properties [1-3].

On the other hand, the thermal diffusivity (α), strictly speaking, is not a characteristic property of composite materials. This is due to the fact that the unsteady heat conduction equation in which α appears as a physical constant is valid only for homogeneous media. Nevertheless, in practice, diffusivity techniques have been successfully applied to many composite materials. For example, Truong and Zinsmeister [4] studied thermal wave propagation in a layered composite material, with the waves running parallel to the layers, and proposed that such materials can be best characterized by two 'diffusivities', one representing the wave attenuation and the other describing the phase shift.

Among all the existing experimental methods of determining the diffusivity of composite materials, the

notably simple and popular one is the flash method of Parker *et al.* [5], originally proposed for homogeneous materials. The method has been extended to the measurement of 'effective' thermal diffusivities of laminates [6], particulate composites [7, 8], and fiber-reinforced composites [9-11]. In the flash method, a high intensity, short duration energy pulse is imposed uniformly on the front face of a test composite specimen. Under adiabatic conditions, except for the initial pulse, the *average* rear face temperature rise is monitored and recorded as a function of time. The 'effective' thermal diffusivity, α_c , can be obtained from the 'half-time', $t_{1/2}$, which is the time required for the rear face to achieve one-half its maximum temperature rise, using the relation [5]

$$\alpha_c = \frac{1.38L^2}{\pi^2 t_{1/2}}, \quad (1)$$

where L is the specimen thickness.

Among the theoretical means of estimating the transient diffusivity of composites (such as using the concept of thermal effusivities [9]), the simplest one is the 'static' diffusivity approximation. This approximation treats the composite material as a homogeneous medium whose 'static' thermal diffusivity, α_s , is defined based on the effective thermal conductivity k_c (from a steady state heat conduction analysis [1-3]), and the effective volumetric specific heat $(\rho c)_c$ (which is a volume average of the volumetric specific heats of the constituent phases) as

$$\alpha_s = \frac{k_c}{(\rho c)_c}. \quad (2)$$

In the case of fiber-reinforced composites, the effective