MEASUREMENT OF COMPOSITE FIBER VOLUME FRACTION USING THERMAL AND ULTRASONIC INSPECTION TECHNIQUES

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INTRODUCTION

Many methods exist for the experimental determination of fiber volume fraction (FVF) in graphite epoxy composites. The most commonly used method of determining composite FVF involves the removal of the matrix by burn off or acid digestion. In addition to being destructive, this technique is time consuming and requires the disposal of toxic waste. Also this technique can be operator dependent (Cilley et al., 1974). Recent work (Zalameda et al. 1992) has shown that the FVF can be determined by measuring thermal diffusivity assuming negligible porosity levels. In addition, work has been done in ultrasonically determining porosity in composites by using a frequency dependent relative attenuation measurement (Hughes et al., 1987). The objective of this work is to develop a nondestructive technique to determine FVF using a dual inspection methodology. The relationship between thermal diffusivity and fiber, matrix and void volume fractions is described in a one dimensional heat flow model where the void volume fraction is determined ultrasonically. The use of a phase lag technique is implemented to make quantitative measurements of thermal diffusivity. These measurements were on composite plates with varying FVF. Diffusivity measurements indicated a nonlinear relation between FVF and measured diffusivity with values ranging from .003 to .007 cm^2/sec. In addition to the thermal measurements, frequency dependent relative attenuation ultrasonic measurements were made within the area to be destructively tested. Results have shown an approximate linear correlation between porosity and attenuation. Results will be presented on 16 and 32 ply composite plates with lay ups of [0/90] 4s and [0/90] 8s and with FVF values ranging from 50 to 75 percent. A comparison of the measurement results to destructive testing is shown and the implementation of the thermal and ultrasonic measurement techniques is described.

FVF SAMPLE PREPARATION

The samples were 16 and 32 ply composite plates with lay ups of [0/90] 4s and [0/90] 8s. The target FVF's were 40, 50, 60, 65, and 70 percent. The low FVF samples were
fabricated by using a cast film of resin which was laid with the tape. The 65 and 70 percent 
FVF were fabricated by prebleeding the plies before curing. A press curing system was 
utilized for consistent thickness. The plates were 30.48 x 30.48 cm in size and were 
sectioned into three sub plates two 15.2 x 15.2 and one 30.48 x 15.2 cm. Using this 
manufacturing technique it was hoped that the plate FVF would be consistent. This was not 
the case, however as the FVF varied throughout the plates, especially for the higher FVF 
plates. Within the plates 1 x 1 cm areas were marked for measurement and eventually 
sectioned for destructive testing. A total of 27 test areas were measured thermally and 
ultrasonically before being destructively tested.

THERMAL DIFFUSIVITY MEASUREMENT SYSTEM

The single point diffusivity measurement system used is shown in figure 1 and consists 
of three main components: the heat source, temperature detector, and computer. The heat 
source is located on the opposite side of the detector for a through transmission 
configuration. The heat source is a 300 watt tungsten filament heat lamp which is controlled 
by the computer. The lamp radiation is focused using a Pyrex lens and modulated by a 
computer controlled shutter. A Polyvinylidene (PVF2) pyroelectric detector was used to 
measure changes in infrared radiation. Pyroelectric detectors offer relatively good 
sensitivity, are rugged, and inexpensive. The infrared detector operates on a change in 
temperature and since the lamp radiation was modulated no detector chopping was required. 
The detector area was 1 mm in diameter and the measured area (field of view) was 
approximately 1.0 cm in diameter. The output of the detector and the input to the shutter 
were digitized at a rate of 256 points per modulation frequency period for four periods.

![Figure 1. Single point thermal diffusivity measurement setup.](image)

The relative phase of the two signals was calculated from their Fast Fourier 
Transforms. The system was calibrated for a bandwidth between .1 - 1 hertz where the 
upper frequency cutoff was due to the mechanical delay of the shutter. Independent phase 
measurements were made of the shutter, PVF2 detector, and associated detector 
electronics. These phase contributions were deconvolved from the measured phase to 
obtain the phase shift due to the presence of the sample. From this phase shift, known 
sample thickness and modulation frequency, the diffusivity of the sample was calculated 
using a one-dimensional single layer heat flow model. The sample’s phase response was 
obtained assuming periodic heating on one surface and no convection losses. This phase 
difference is found to be: