POSTER

NON-DESTRUCTIVE EVALUATION OF CARBON-CARBON COMPOSITES USING PULSED VIDEO THERMOGRAPHY

David T. Marx*, Robert P. Brady**, and Manohar R. Kulkarni**

*Materials Technology Center
**Department of Mechanical Engineering and Energy Processes
Southern Illinois University at Carbondale
Carbondale, Illinois 62901

Introduction

Pulsed video thermography (PVT) is an emerging non-destructive evaluation technique that has the potential to be used for the rapid, on-line, quality assessment of a test part's thermal properties, material integrity and other related parameters. Recent cooperative research performed by the authors and work cited in the literature has shown that PVT can not only be used as a relatively inexpensive alternative to determining point thermal properties, but it can also generate correlated parameters (e.g., porosity). The PVT technique is based on the well-researched flash thermal diffusivity technique described below.

The flash method for determining thermal diffusivity was developed by Parker *et al.* [1] about thirty-five years ago. The technique has become a well-developed, standard technique because of its relative ease, ability to measure a wide-range of diffusivity values, small sample size, reliability, and reproducibility of results. In this method, a small disc is machined with two parallel, flat faces. The sample is placed inside a tube furnace within a bell jar. The ambient temperature of the sample may be varied from room temperature to 2000 °C in either a vacuum or inert gas environment. To carry out the test, a powerful laser pulse (~ 1 msec in duration) uniformly illuminates one face of the disc while the other face is continuously monitored with an infrared detector. The signal from the infrared detector is amplified, recorded on an oscilloscope, and sent to computer for analysis.

Thermal diffusivity is determined from the temperature-rise curve by using the solution of the transient heat flow equation with suitable initial and boundary conditions. These conditions and other physical assumptions include: unidirectional heat flow, no heat loss from the sample surfaces, absorption of the pulse energy in a very thin layer, uniform pulse absorption at the front surface, and physical property invariance with temperature during the experiment. The temperature rise curve is written as

$$(1)\quad \frac{(\Delta T)}{(\Delta T)_{\max}} = 1 + 2\sum_{n=1}^{\infty}(-1)^n \exp(-n^2\pi^2\,\alpha\, t / \ell^2)$$

where α is the thermal diffusivity, t is the time elapsed after the pulse, and ℓ is the specimen thickness. From this equation, the thermal diffusivity may be determined at any time t_x along the temperature rise curve by

$$(2)\quad \alpha = A_x \ell^2 / t_x$$

where A_x is a predetermined constant. and the x in the subscript corresponds to a percentage of the maximum temperature rise.

For cases where the heat pulse overlaps the observed temperature rise of the specimen (as is the case in our PVT technique), a finite heat pulse correction formula is employed [2]:

$$(3)\quad \alpha = A_{x_1} \ell^2 / (A_{x_2} t_x - t_p)$$

where t_p is the heat pulse duration.

Experimental Details

The PVT Laboratory of Southern Illinois University at Carbondale has developed a novel computer work station that utilizes simple off-the-shelf components with inexpensive liquid crystal technology for the quantitative characterization of the material properties of composites. The system is user friendly, portable, and allows for automated thermal image capture. Figure 1 shows the core PVT apparatus. The method utilizes the application of powerful lamps to externally apply a heat **pulse** to introduce temperature transients at the surface of the specimen. The resulting thermal behavior is **video** captured through the response of a thin coating of liquid crystals applied to the surface. The striking colors of the captured images are temperature calibrated so that **thermography** techniques can be used to determine thermal properties such as diffusivity α or to quantitatively characterize the existence of defects such as delaminations and large pores.

Results and Discussion

Samples used in this study were machined in the form of small discs from eight different, commercially-produced, carbon-carbon composites. The diameter and thickness of each disc was approximately 10 mm and 5.0 mm, respectively. The exact fabrication method and composition of these composites is both unknown to the authors and proprietary. These samples were only chosen to provide a range of thermal diffusivity values for comparison of the two measurement techniques used in this study.

The first two samples were used to determine the constants A_{x_1} and A_{x_2} in Equation (3) used in the evaluation of data collected using PVT. The diffusivities measured using the two techniques are listed in Table 1. These preliminary results are in fairly good agreement with the exception of sample G. The PVT technique is currently being improved via the use of wider temperature range liquid crystals and better control of the flash lamp heat input. At present, the duration of the heat pulse is longer than the lamp on-time since the lamp filament remains hot for some time after the lamps are turned off. Another improvement may be achieved via employment of an infrared thermography system, eliminating the need for liquid crystals.

Conclusions

This paper will present results obtained in the following areas: quantitative application of the PVT method for the determination of the limits and desirable conditions of this technique concerning heretofore superficially investigated materials such as carbon-carbon composites, the development of a procedure to be used in obtaining property maps as a diagnostic quality assurance tool, and the use of a new calibration technique for liquid crystal thermography. The results obtained via PVT will be compared with those obtained via laser-based flash thermal diffusivity.

References

1. W. J. Parker, C. P. Jenkins, and G. L. Abbott. "Flash Method of Determining Thermal Diffusivity, Heat Capacity, and Thermal Conductivity." *J. Appl. Phys.*, 32, 1679 (1961).

2. R. E. Taylor and L. M. Clark. "Finite Pulse Time Effects in the Flash Diffusivity Method." *High Temperatures-High Pressures*, 6, 65 (1974).

Figure 1. Pulsed video thermography thermal diffusivity test apparatus

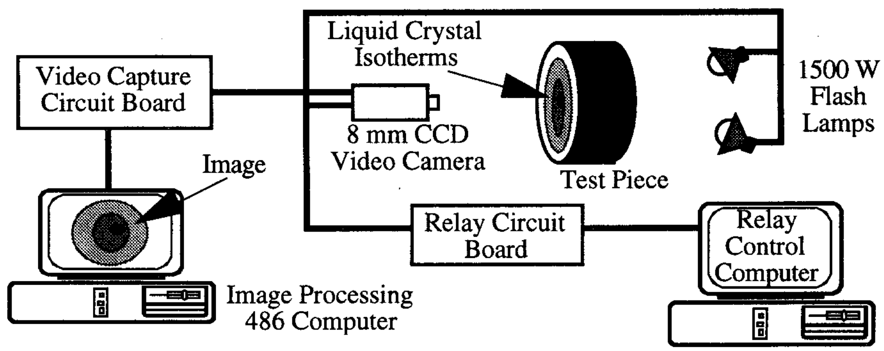

Table 1. Comparison of carbon-carbon specimen diffusivity results obtained using pulsed video thermography (PVT) and laser-based flash diffusivity

Specimen	PVT Diffusivity ($\times 10^{-6}$ m^2/sec)	LASER-based Flash Diffusivity ($\times 10^{-6}$ m^2/sec)
A	[a]	26.7
B	[a]	5.8
C	9.5	9.8
D	17.0	20.0
E	11.2	9.7
F	18.5	20.7
G	31.6	15.0
H	12.3	10.0