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GRAPHITE/EPOXY COMPOSITE LAMINATES WITH CO-CURED INTERLAMINAR DAMPING LAYERS

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ABSTRACT

Damped composite laminates were fabricated by co-curing viscoelastic damping film with graphite/epoxy prepreg plies. The dynamic response of the damped plates was measured using an impulse response technique and compared with the response of similar undamped laminates. Modal damping was computed from the frequency response data. Micrographs of the damped laminates showed that the damping layers retained their integrity during the fabrication process. The layers significantly increased the damping in the composite laminates. The use of the constrained viscoelastic film as an integral part of composite structures appears to be a feasible approach to passive vibration control. Composite plates manufactured with co-cured damping layers may have commercial applications in cases where light weight, strength and vibration and noise reduction are important considerations.

INTRODUCTION

Vibration control is an issue of prime importance in many structures subjected to external loads or internally moving components. Often, the control of vibration is of such critical importance that active vibration control systems are incorporated into the structure. While they may be effective, the use of active control systems can add significant complexity, weight and cost to a design. Whenever possible, it is usually more desirable to reduce vibration problems using passive methods such as dampers, additive damping material, or highly damped structural materials.

Composite materials have important potential benefits in the area of passive vibration control. Advanced composite materials can have significantly greater specific stiffness and damping than traditional structural materials such as aluminum [1, 2]. An important aspect of composites is that, like the stiffness properties, the damping capacity of composites can be controlled by the selection of materials and layup. Composite material systems can be engineered to control specific vibration problems while addressing other concerns such as stiffness, strength and toughness. Previous experiments have shown that the interlaminar fracture toughness of a graphite/epoxy laminate is increased by as much as a factor of 10 by curing an adhesive interply layer in the composite [3]. In addition, recent analytical studies have shown that the use of a constrained viscoelastic layer in a composite laminate can significantly increase modal damping [4].

The aim of this study was to experimentally investigate the use of a constrained viscoelastic damping material for passive vibration control of graphite/epoxy composite structures. The damping material was co-cured with the composite to form laminates with internal damping layers at various locations. The dynamic response of the composite plates was measured using an impulse response technique.

METHODS

Fabrication of Damped Laminates

Composite laminates with various layups were manufactured by co-curing graphite/epoxy composite in pre-preg form with a polymer damping material. The laminates consisted of T300/934 graphite/epoxy with a 60% fiber volume ratio combined with Scotchdamp ISD110 damping film (3M Corp., St. Paul, Minnesota). Two different laminates were fabricated with the damping film, a $[+45_2/-45_2/i/+45_2/-45_2]_{sym}$ laminate, and a $[+22.5_2/-22.5_2/i/+22.5_2/-22.5_2]_{sym}$ laminate, where *i* refers to the interlaminar damping layer. Two additional laminates were fabricated with the same layup, but excluding the damping layers, and one laminate with interlaminar damping layers was fabricated for microscopic examination. All laminates were cured in a press at 175°C (350°F) and 345 kPa (50 psi). After curing, the laminates were trimmed to produce 28cm x 28cm plate specimens.

Vibration Experiments

The panels were vibration tested in the free-free mode using an impulse response technique. The panels were supported from one corner by a very flexible rubber band, such that the fundamental mode of the panel/rubber band system had a frequency of less than 1 Hz. Impulse response tests were conducted by impacting the center of the plate with an instrumented hammer, and measuring the response with an accelerometer at one of four corner locations shown in Figure 1. The four locations were chosen to check the repeatability of measurements. The accelerometer had a mass of 1.0 gm, compared to a mass of approximately 270 gm for the plate specimens.

The recorded impulse response data consisted of the averaged force and acceleration history from 10 impacts. Data was recorded with a digital data acquisition system using an acquisition rate of 10^5 samples/sec and a record length of 16384 samples, for a total duration of .16384 sec. The data was transferred to a computer to calculate the frequency response functions and damping in the frequency range up to approximately 1500 Hz.

Damping Computation

For the purpose of computing damping, it was assumed that in the vicinity of a resonance the response was dominated by a single mode, which could be modeled as a single degree of freedom, viscously damped system. A modification of the standard Nyquist circle fit method [5] was developed to compute the specific damping capacity (SDC), ψ [6].

The effect of the damping layer on the plates was evaluated by comparing the SDC for damped and undamped plates as a function of frequency. The accuracy of the damping results was then evaluated by synthesizing the frequency response function using the computed modal constants, and comparing the result with the measured data.

RESULTS

There appeared to be no damage to the interlaminar damping layers as a result of the fabrication process. Micrographs of sections cut from one of the plates showed that the damping film retained its integrity, with no apparent delamination between the film and the adjacent composite plies (Figure 2). Rough areas visible in the central region of the damping layer shown in Figure 2 are believed to be a result of the micrograph specimen preparation process.

The synthesized frequency response functions were very close to the measured data (Figure 3), indicating that the assumed modal model was a good representation for the behavior of both the damped and undamped laminates.

The modal specific damping capacity for the undamped laminates was relatively constant over the frequency range examined (Figures 4 and 5). At the low end of the frequency range the SDC for the damped and undamped plates were comparable. The SDC for the damped plates increased with frequency, however, so that at the upper end of the frequency range examined the SDC for the damped laminates was 2 to 3 times that of the undamped laminates. The ±22½ laminates displayed some highly damped low frequency modes. It is not known whether this was a real phenomenon related to the material, or if it was an artifact due to rotational vibration of the plate/rubber band system. Apart from these low frequency modes, results for both layups were very similar, in both the damped and undamped laminates.

A qualitative measure of the effect of the damping layer can be obtained by comparing the acceleration time histories of the damped and undamped plates. The acceleration response decayed much faster with the damped plate than with the undamped plate (Figure 6).

DISCUSSION AND CONCLUSIONS

The approach of co-curing a damping film with composite pre-preg appears to be very effective as a passive vibration control measure. The damping layers significantly increase the modal damping in graphite/epoxy laminates which are already relatively highly damped. Although it required a number of trials to learn how to make the laminates, the processing is relatively straightforward. Micrographs indicate that the damping layers maintain their integrity and bond well to the adjacent composite plies.

While the constrained viscoelastic layers increase the structural damping in the laminates, further work should be done to determine how the layers influence the compressive strength, stiffness and impact resistance of the materials.

Determining the effect of a constrained viscoelastic layer on the dynamic response of composite structures is complex. The energy dissipation comes primarily through shear deformation of the layer. An important advantage of composite materials is that it is possible to tailor the material to optimize the in-plane shear and resulting damping. Methods of predicting the damping capacity of composites, and the damped dynamic response of structures are important if their benefits are to be realized.

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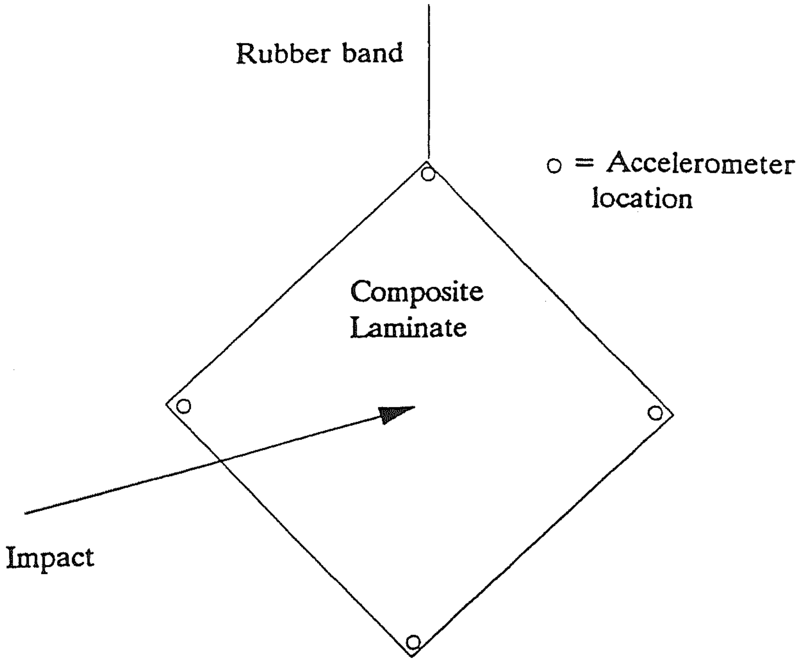

Figure 1: Schematic of the experimental configuration. Separate experiments were done with the accelerometer at each of the four locations shown.

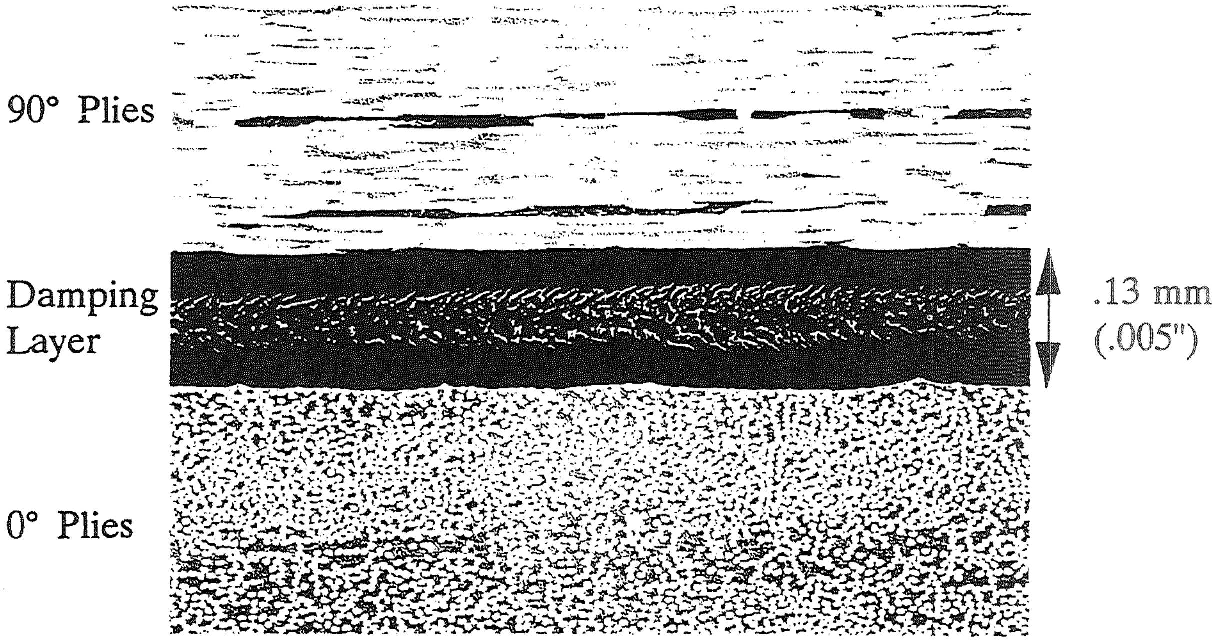

Figure 2: Micrograph of the damping layer between composite plies after the fabrication process. The damping layer appears to retain its integrity. The rough area at the center of the layer is believed to be a result of the micrograph specimen preparation process.

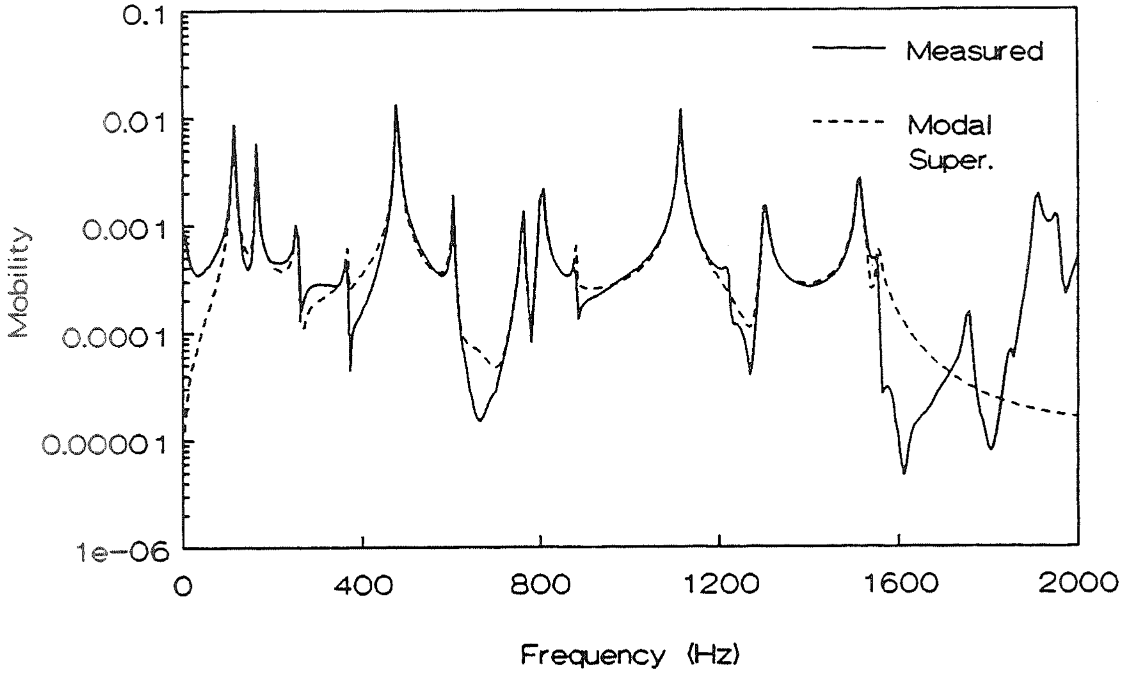

Figure 3: Comparison of the measured mobility function (velocity/force) with the predicted funtion using the modal superposition procedure for a ±45 laminate without damping layers.

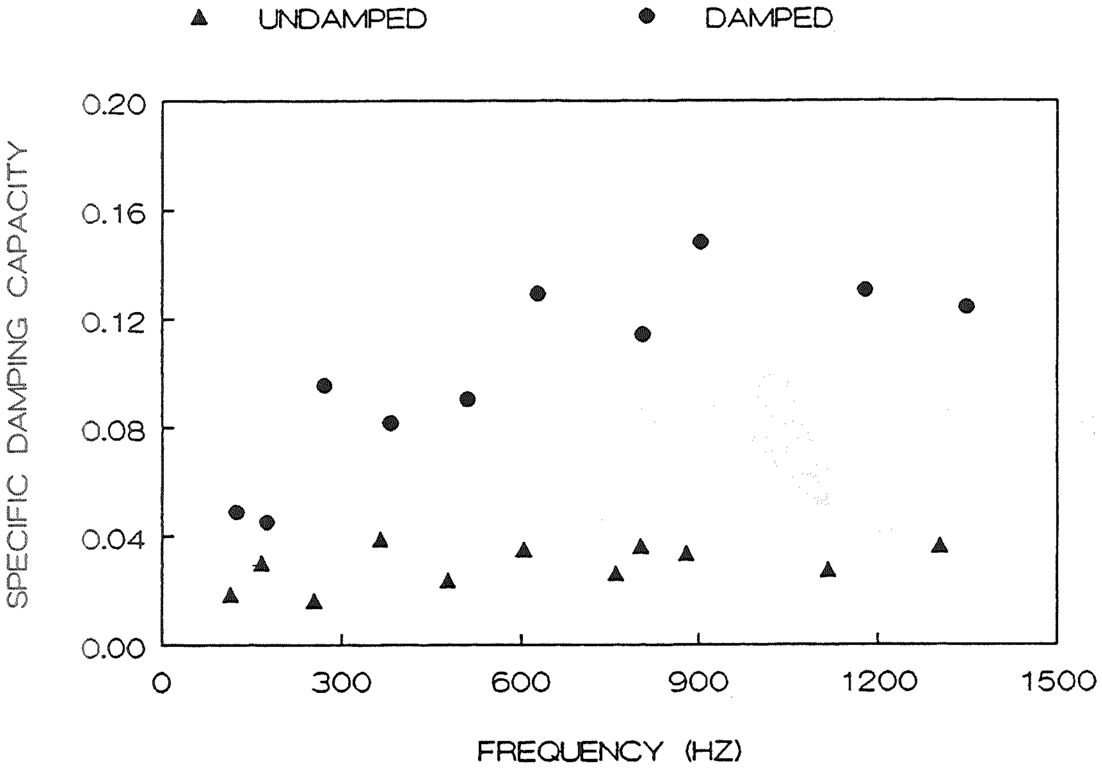

Figure 4: Modal specific damping capacity computed from the experimental data for the damped and undamped $[+45_2/-45_2/(i)/+45_2/-45_2]_{sym}$ laminates. The specific damping capacity for the damped laminate is significantly higher than that of the undamped laminate, and increases at higher frequencies.

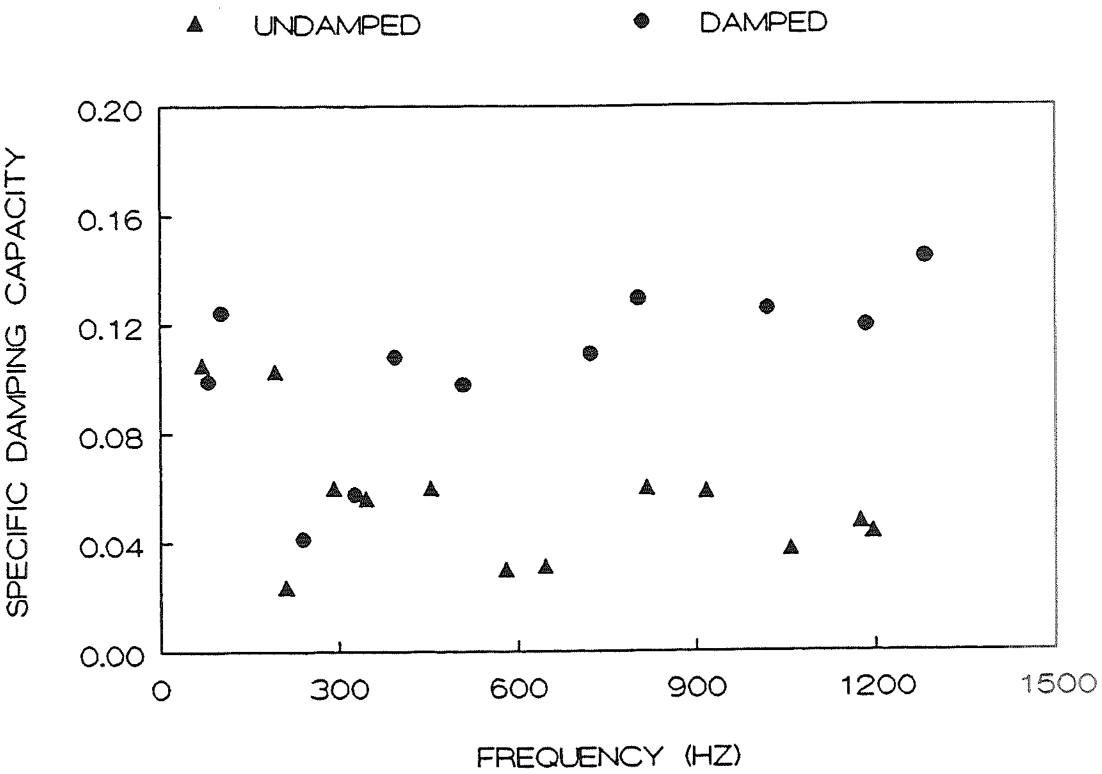

Figure 5: Modal specific damping capacity computed from the experimental data for the damped and undamped $[+22.5_2/-22.5_2/(i)/+22.5_2/-22.5_2]_s$ laminates. Apart from low frequency region, the specific damping capacity is significantly higher for the damped laminate.

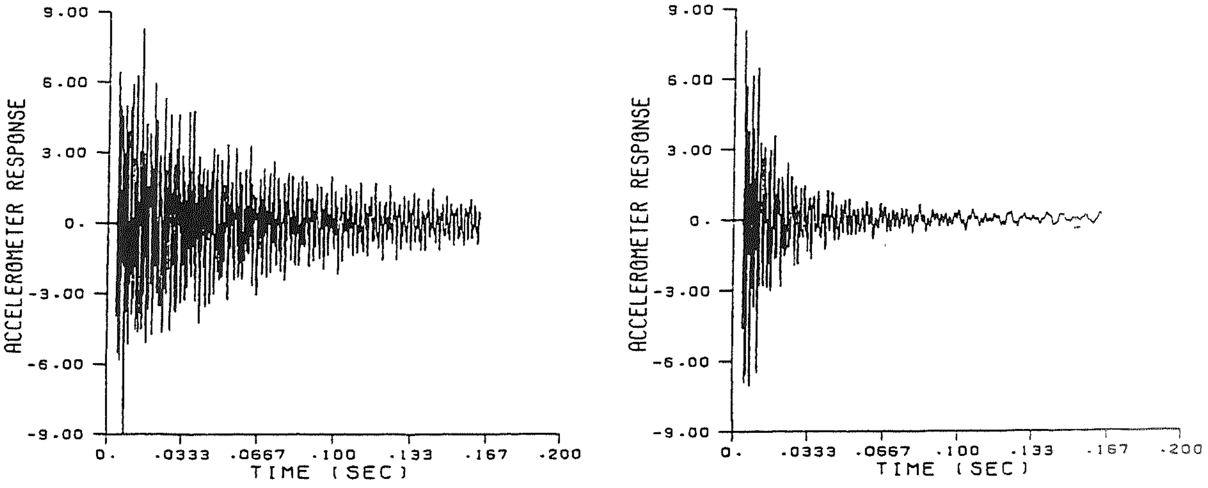

Figure 6: Accelerator time response for the undamped (left) and damped (right) ±45° laminates. There is a clear increase in the rate of decay for the damped laminate.