Journal of Testing and Evaluation, May 2006, Vol. 34, No. 3
Paper ID JTE12186
Available online at: www.astm.org

J. D. Lincoln,[1] *L. E. Rieger,*[1] *and J. C. Earthman*[1]

Instrumentation for Determining the Local Damping Capacity in Honeycomb Sandwich Composites

ABSTRACT: A mechanical percussion probe originally designed for determining the damping capacity of dental implants has been adapted to assess the damping capacity in a localized area of honeycomb sandwich composites without inflicting damage on the structure. The new instrumentation is light, portable, and inexpensive compared with other testing techniques. Furthermore, it allows quick access to areas not easily accessible by ultrasonic methods. The damping capacity of honeycomb sandwich composite structures is of interest to engineers as it reflects the ability of a material to absorb and isolate vibration. Honeycomb sandwich structures with various damping treatments were constructed and accurately evaluated with the instrumentation. Detection capabilities and limitations were also evaluated.

KEYWORDS: honeycomb, prepreg, loss factor, local damping capacity, periometer

Introduction

Honeycomb sandwich components are attractive materials for lightweight constructions in aerospace, boating, and civil and automotive engineering. Typical sandwich constructions exhibit two facings, relatively thin but having high strength and stiffness, enclosing a honeycomb core structure, relatively thick but lightweight, and with high strength in the direction normal to the facings. The layers of the sandwich material must be bonded together, either with adhesives or mechanically, so that their composite properties can be realized. The concept behind a sandwich panel is that the facings carry flexural stress while the core carries shear stress. The particular type of sandwich panel used in the present work utilizes two layers of fiberglass facings impregnated with phenolic resin on each side of a Nomex™ honeycomb core. This construction is typical of an aircraft interior sandwich panel. Although honeycomb sandwich constructions exhibit moderate-loss damping characteristics, optimizing loss factors with additional treatments is of interest. While previous investigations have explored models and damping treatments for composite materials [1–5], none have yet explored the interlaminar integration of damping treatments in the present investigation. Vibrations in these structures cause both eventual degradation of bonds between adhesive layers and the honeycomb as well as undesirable acoustic effects. The instrumentation developed in this circumstance has been adapted for determining the damping capacity of a specific region of the aforementioned honeycomb structures. The "local" region where the equipment is determined effective is a region having a depth of 4 mm from the surface and a radius of 5 cm from the probe impact point (determined experimentally). Similar equipment previously has been shown to be able to detect damaged portions of composite lamina near the point of impact [6]. Contrary to other damping test methods, the present equipment is portable, lightweight, and can assess loss factors rapidly. The purpose of this work was to examine the utility and explore the limitations of the instrumentation as applied to integrally damped composite sandwich structures.

Experimental

Equipment

The instrumentation consists of the periometer percussion probe (U.S. Patent No. 6120466) interfaced with a computer having custom data-acquisition software that was developed using the LabVIEW® programming environment (see Fig. 1). The probe sends a rod with an electromagnetic coil, impacting the sample 16 times in 4 s; the impact generates a signal that is sent to the computer. The computer analyzes 10 of the 16 impacts and generates a graphical representation (returned energy versus time) of the material's response to the percussions. By analyzing the energy input and the energy returned, the software arrives upon a loss factor for the material. The duration of each percussion response is approximately 0.6 ms. In terms of loading rate, this response corresponds roughly to a vibration loading frequency of 1700 Hz. The sample panel is mounted in an angle vise with rubber grips and the probe is brought up to the surface in the center of the panel. For consistency, the vise is tightened with the same torque (2765 cm g) each time, and both the probe and vise are leveled to ensure that alignment is perpendicular. Additionally, the tip of the probe is 2.5 cm in diameter and made from Teflon™ to reduce external disturbances and aid in alignment. The probe is allowed to warm up for 30 min prior to use to ensure consistent test results. Both top and bottom surfaces of the panels were tested, and each test result is the average of five readings.

Materials

Sandwich panels were constructed with J. D. Lincoln, Inc. type L-591-7781 toughened phenolic prepreg (preimpregnated, woven

---

Manuscript received August 28, 2003; accepted for publication October 6, 2005; published December 2005.

[1] Department of Chemical Engineering and Materials Science, University of California, Irvine, CA.

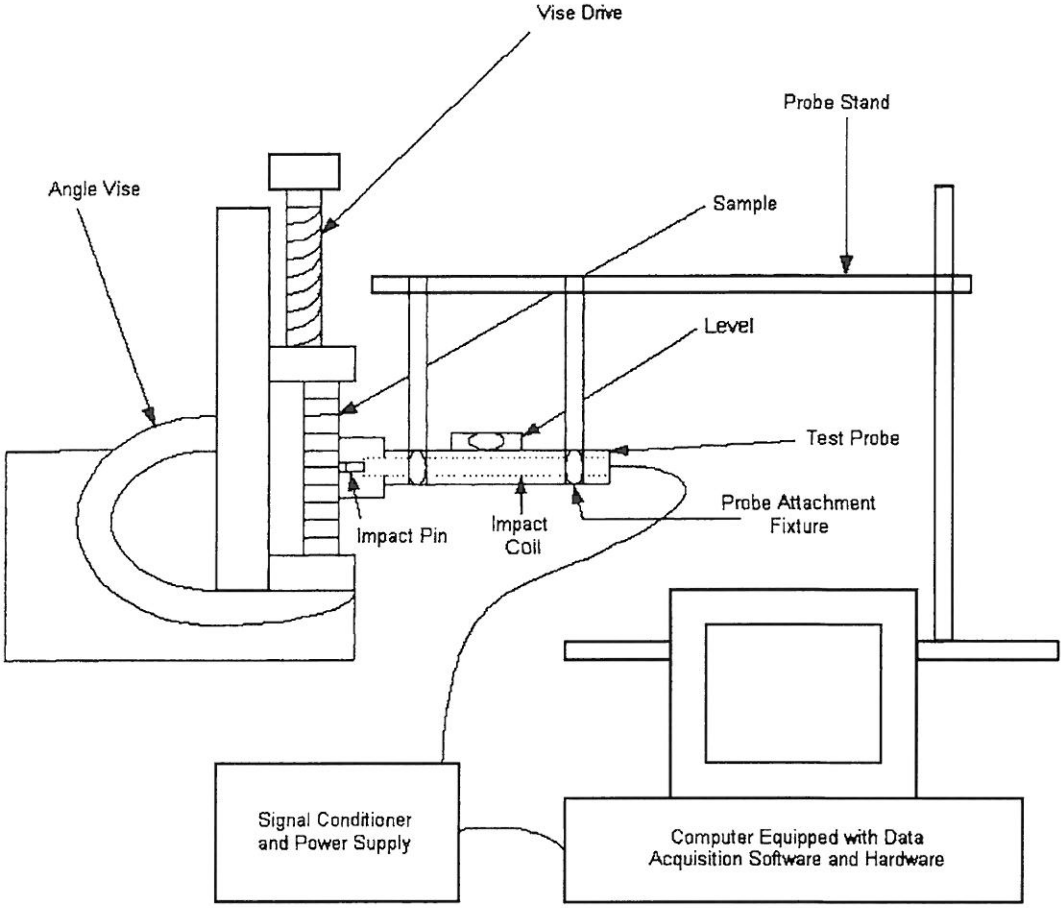


FIG. 1—*Schematic of the present test configuration.*

fiberglass with a partially advanced polymer matrix). Two plies of prepreg sandwiched a Nomex™ core. Nomex™ is a high strength paper dipped in phenolic resin, cured, and shaped into a honeycomb core. The prepreg was aligned with the core such that the warp direction of the fiber was against the core, aligned parallel to the ribbon direction of the honeycomb. A damping film of the type J. D. Lincoln, Inc. L-601 was used to treat the panel at various layers. Type L-601 has been characterized in terms of loss factor, adhesion characteristics, and glass transition temperature. Additionally, one surface of panels 1 and 2 was covered with a polyvinyl fluoride film, Tedlar®, to simulate an aircraft interior scenario. Table 1 lists the weights and thickness of the individual layers used in the panels. The panels were manufactured in a laboratory press, cured 1 h at 135°C, with 0.276 MPa pressure.

Calibration

Two samples, one of high loss (damped phenolic panel), and one of low loss (acrylic sheet) were sent to an independent lab to be evaluated for dynamic loss factor per ASTM E 756-98 at room temperature over a range of 1–3 kHz. Data generated from the above tests were used to calibrate the instrument. Both the ASTM test method and the present investigation examine flexural vibration modes. The same panels were then retested yielding the data in Table 2. These data show good agreement for the systems examined in this experiment.

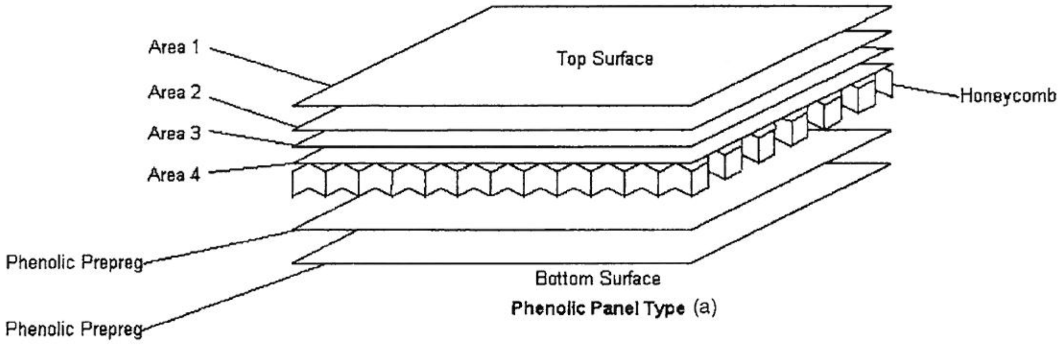
Damping Treatments

Table 3 describes panel constructions and damping treatments. The instrumentation was applied to investigate the response properties of panels with treatments integrated at various layers. Panels 1 and 2 had damping treatments embedded at various levels in the surface layer on one side of the sandwich panel. Panel 3 had no damping layer, serving as a control panel. Panels 4, 5, 5.4, and 5.5 (Type B) had damping treatments embedded in the honeycomb core. Panels 5.4 and 5.5 were identical to panel 5, but had different reduced size to determine the relationship between loss factor and panel dimensions.

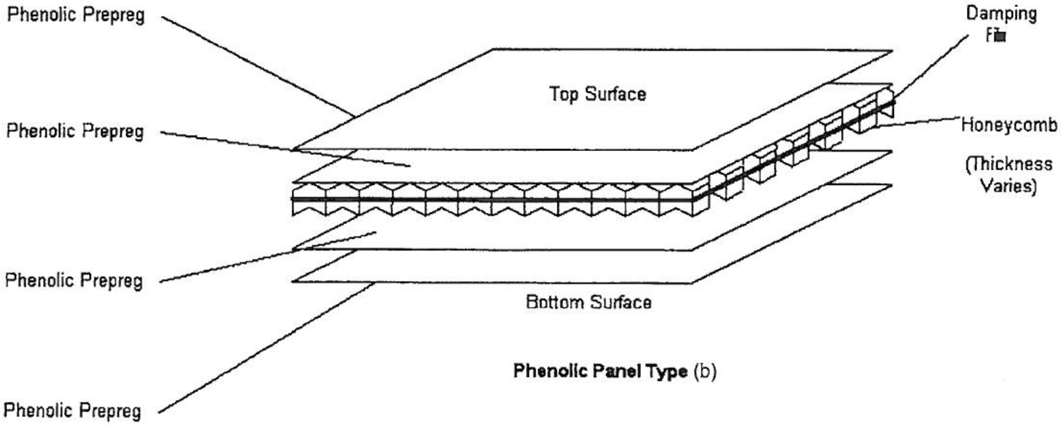
Experimental Results

Loss Factor Values for Honeycomb Sandwich Panels

Table 4 gives the average loss factor results for all of the panels tested in the present work. Loss factors are also plotted against both damping layer depth (Fig. 3) and panel dimensions (Fig. 4). These figures show two interesting phenomena. Figure 3 demonstrates a general decrease in the loss factor with respect to the distance between the damping layer and the point of impact on the external surface. The equipment confirms the expected trend that higher



Phenolic Panel Type (a)



Phenolic Panel Type (b)

FIG. 2—*Honeycomb sandwich panel constructions used in the present investigation.*

local damping is expected when the damping layer is nearer to the source of disturbance [11]. Figure 4 demonstrates that increasing the dimensions of a square panel results in a decrease in loss factor. These data are most likely a result of the increasing relative compressive force imposed on the panel by the sample grips, as well as a decrease in the modal frequency vibration resulting from the increased forces.

TABLE 1—*Physical characteristics of the test materials.*

Material	Description	Thickness (mm)	Weight (gm^{-2})
Tedlar	Polyvinyl Flouride Surfacing Film	0.05	20
601	Damping Film, Acrylic	0.20	283
591–7781	Phenolic Prepreg, Fiberglass	0.22	460
Honeycomb Core	Nomax™, Phenolic	Varies	Varies

TABLE 2—*Calibration loss factors and tested loss factors (unitless).*

Panel Type	Calibrated Value	Standard Deviation	Tested Value	Standard Deviation
Acrylic	0.0335	0.0011	0.0247	0.0003
Phenolic	0.1351	0.0014	0.1359	0.0006

Discussion

Several adjustments in the experimental setup were made to increase the accuracy and consistency of results, among them—constant-torque sample mounts, probe grips, probe level, and allotted warm-up time. While standard deviations all fell within 1.5 % of individual loss factor readings, consecutive readings varied as much as 10 %. As such, five readings on each of three panels (with the exception of panels 5.4 and 5.5, refer to Table 4) were averaged to account for this variance. Taking more than five readings on each panel did not yield increased accuracy in data.

The data in Table 4 show that panels 1 and 2 have very similar damping capacities when evaluated with the periometer. Based on this, the preferable construction is panel 1, as interlaminar shear strengths are reduced in panel 2 (as the damping film inhibits adhesive bonding between prepreg layers). Panel 4 also exhibits high loss characteristics. As in the case of panel 2, however, damping comes at the expense of mechanical strength. For a more realistic evaluation of local damping characteristics, honeycomb paneling needs to be evaluated in its functional environment, a technique before observed in aerospace circumstances [5,7,8]. An in-place evaluation would prove more valid as it would incorporate local bonding fixtures or stresses imposed on the structures into the data. The periometer could serve effectively as a portable test unit for such an evaluation.

One should consider whether the addition of weight justifies the increased damping capacity for determining the ideal damping

TABLE 3—*Panel constructions.*

		Damping Treatment Details				Dimensions (cm)	
Panel	Figure	Area 1	Area 2	Area 3	Area 4	L × W	Core Thickness
Panel 1	2A	Tedlar	601	591-7781	591-7781	7.6 × 7.6	1.15
Panel 2	2A	Tedlar	591-7781	601	591-7781	7.6 × 7.6	1.15
Panel 3	2A	Tedlar	Not Used	591-7781	591-7781	7.6 × 7.6	1.15
Panel 4	2B	N/A	N/A	N/A	N/A	7.6 × 7.6	0.95 and 0.32
Panel 5	2B	N/A	N/A	N/A	N/A	7.6 × 7.6	0.64 and 0.64
Panel 5.4	2B	N/A	N/A	N/A	N/A	5.1 × 5.1	0.64 and 0.64
Panel 5.5	2B	N/A	N/A	N/A	N/A	2.5 × 2.5	0.64 and 0.64

treatment for a honeycomb sandwich composite. In the present study, constructions increased in weight by 10.4 %. Future experiments will compare damping reductions and weight trade-offs to optimize treatments in honeycomb sandwich composites; it should be noted here that there are a variety of other treatment methods under examination [3,5,9,10]. This optimization will depend greatly on the conditions in the application involved.

TABLE 4—*Loss factor data.*

		Data, Top Surface (avg.)		Data, Bottom Surface (avg.)	
Panel	Panels Tested	Loss Factor	Std. Dev.	Loss Factor	Std. Dev.
Panel 1	3	0.1298	0.0002	0.0803	0.0003
Panel 2	3	0.1215	0.0003	0.0915	0.0002
Panel 3	3	0.0787	0.0004	0.0819	0.0007
Panel 4	3	0.1229	0.0006	0.0803	0.002
Panel 5	3	0.0756	0.0003	0.0834	0.0002
Panel 5.4	1	0.0893	0.0007	0.1012	0.001
Panel 5.5	1	0.1564	0.0022	0.1505	0.0012

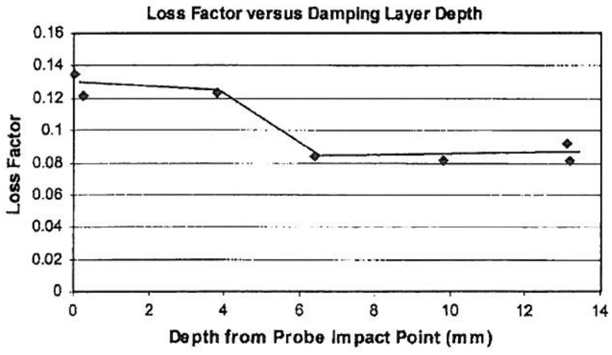


FIG. 3—*Perimeter sensitivity trend with respect to depth.*

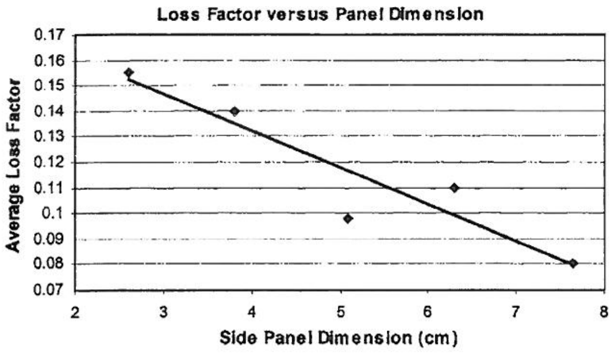


FIG. 4—*Loss factor dependence on panel dimensions.2*

The present data demonstrate that the periometer is capable of determining the local damping capacity of honeycomb sandwich panels. In applying this instrumentation, three significant limitations were observed. First, the instrumentation readily detects trends in damping-layer depth in honeycomb sandwich panels, indicating a depth limitation of about 4 mm. Assuming that vibrations generated from the test impact propagate elastically, normal to the panel facings, one would expect identical loss factor results from top and bottom sides of the same panel. This would also be expected if an increased damping resulted from application of a damping layer in an area of high stress density (the panel surface) as in the present investigation. Since similar readings were not observed from both sides of panel, it can be concluded that this is a depth limitation. Figure 3 demonstrates that the detection capabilities of the instrument extend to about one-quarter of the depth of the panel (4 mm). At this depth, loss factor data are similar to those of the undamped control panel 3 (see Fig. 4). The second limitation observed in the current experimental setup is that sample size has an effect on the results; it is clear that higher damping indications are achieved with smaller panel dimensions. However, similar readings to undamped panels arise when the distance from the impact probe of the periometer reaches about 5 cm. There are two plausible explanations for this behavior. First, the increased compressive force imposed on smaller panels fixed with the same torque may have decreased the damping capacity. Second, the modal flexural vibration frequencies likely decrease with increasing panel dimensions. Since loss factor decreases with decreasing modal frequency, this would have resulted in the observed trend. In both circumstances a limitation of 5 cm from the impact probe is observed. Combining the first and second limitations, it can be concluded that the local damping capacity measured with this equipment falls within a depth of 4 mm and a radius of 5 cm from the impact probe. In an on-site application of the equipment, the same issues would arise near panel fixture points. The maximum sample size for this experiment is 9.6 cm square. Panels in application would certainly have a gradient of damping capacities, as attachments or fixture points would change the local damping capacity. Finally, the loading rate (frequency) the instrumentation uses for evaluation of damping capacity is currently fixed. The perimeter could be improved if adapted to provide data at various loading rates.

Conclusion

The periometer may be used to evaluate accurately the damping characteristics of damped and undamped honeycomb sandwich composites. The present data show the detection capabilities of the instrument include a depth detection of 4 mm, a loss factor dependent on panel dimensions, and a fixed impact frequency. The capabilities of the periometer may be adjusted for a particular application.

Acknowledgments

Thanks are extended to J. D. Lincoln, Inc., Newport Coast Oral Facial Institute, and Damping Technologies for their assistance in this experiment.

References

[1] Fausett, D. W., Fausett, L. V., and Dubbelday, P. S., "Comparison of Constrained Layer Damping Models," *J. Acoust. Soc. Am.*, Nov. 15, 1986, Vol. 80, Issue S1, p. S121.

[2] Maheri, M. R. and Adams, R. D., "Finite-Element Prediction of Modal Response of Damped Layered Composite Panels," *Compos. Sci. Technol.*, Vol. 55, 1995, pp. 13–23.

[3] Kwak, G. H., Inque, K., Tominaga, Y., Asai, S., and Sumita, M., "Characterization of the Vibrational Damping Loss Factor and Viscoelastic Properties of Ethylene-Propylene Rubbers Reinforces with Micro-Scale Fillers," *J. Appl. Polym. Sci.*, Vol. 82, 2001, pp. 3058–3066.

[4] McDaniel, J. G., Dupont, P., and Salvino, L., "A Wave Approach to Estimating Frequency-Dependent Damping Under Transient Loading," *Journal of Sound and Vibration*, Vol. 231, No. 2, 2000, pp. 433–449.

[5] Skullestad, A. and Hallingstad, O., "Vibration Parameters Identification in a Spacecraft Subjected to Active Vibration Damping," *Mechatronics*, Vol. 8, 1998, pp. 691–705.

[6] Stanley, B. D., Bustemante, L., and Earthman, J. C., "Novel Instrumentation for Rapid Assessment of Internal Damage in Composite Materials," *The Minerals, Metals and Materials Society*, 1997, pp. 97–100.

[7] Rittweger, A., Albus, J., and Hornung, E., "Passive Damping Devices for Aerospace Structures," *Acta Astronaut.*, Vol. 50, No. 10, 2002, pp. 597–608.

[8] Rao, M. D., "Recent Applications of Viscoelastic Damping for Noise Control in Automobiles and Commercial Airplanes," *2001 India-USA Symposium on Engineering Trends in Vibration and Noise Engineering*, 2001.

[9] Finegan, I. C. and Gibson, R. F., "Analytical Modeling of Damping at Micromechanical Level in Polymer Composites Reinforced with Coated Fibers," *Compos. Sci. Technol.*, Vol. 60, 2000, pp. 1077–1084.

[10] Finegan, I. C. and Gibson, R. F., "Recent Research on Enhancement of Damping in Polymer Composites," *Compos. Struct.*, Vol. 44, 1999, pp. 89–98.

[11] Wu, L., Agren, A., and Sundback, U., "A Study of the Initial Decay Rate of Two-Dimensional Vibrating Structures in Relation to Estimates of Loss Factor," *Journal of Sound and Vibration*, Vol. 206, No. 5, 1997, pp. 663–684.