N91-10319

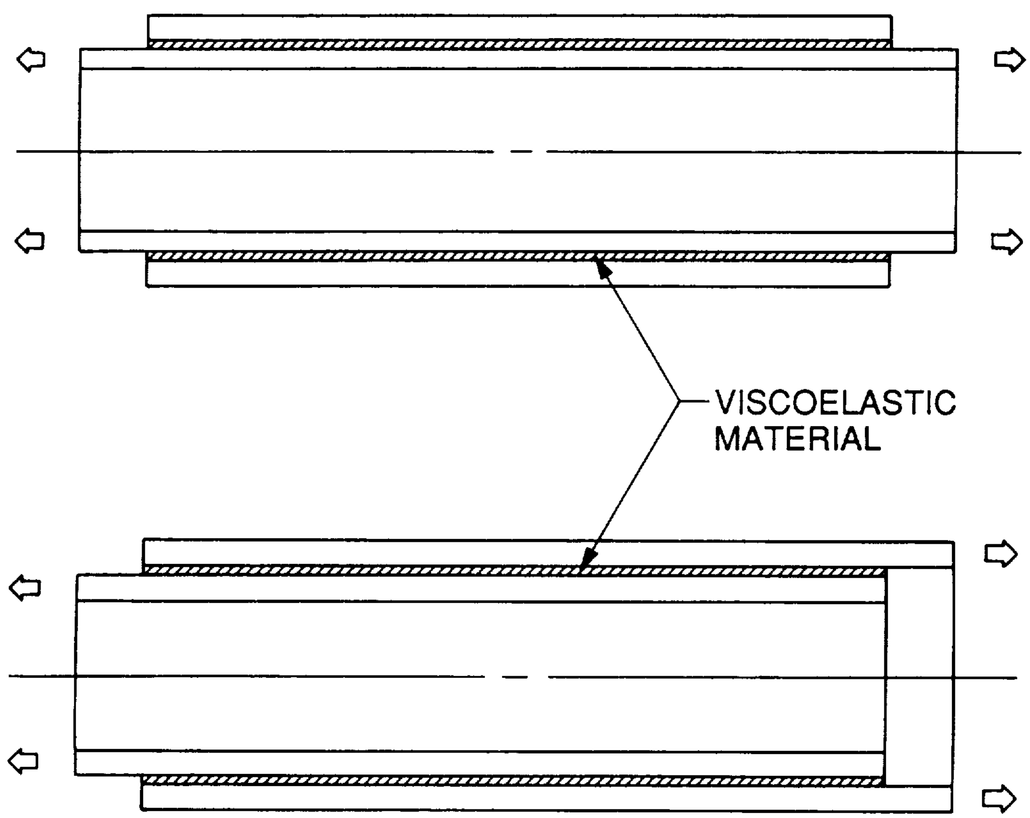
Analysis of Elastically Tailored Viscoelastic Damping Member

G-S. Chen and B.P. Dolgin

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

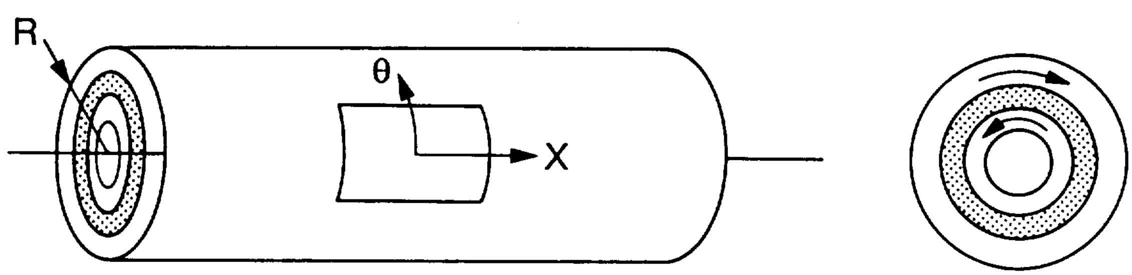
Introduction

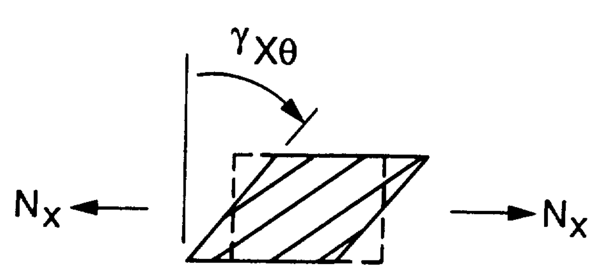
For more than two decades, viscoelastic materials have been commonly used as a passive damping source in a variety of structures because of their high material loss factors. In most of the applications, viscoelastic materials are used either in series with or parallel to the structural load path. The latter is also known as the constrained-layer damping treatment[1,2]. The advantage of the constrained-layer damping treatment is that it can be incorporated without loss in structural integrity, namely, stiffness and strength. However, the disadvantages are that (1) it is not the most effective use of the viscoelastic material when compared with the series-type application, and (2) weight penalty from the stiff constraining layer requirement can be excessive. To overcome the disadvantages of the constrained-layer damping treatment, a new approach for using viscoelastic material in an axial-type structural components, e.g., truss members, was studied in this investigation.



Elastic Tailoring in Composite Structures

It is well known that, with the properly arranged orientation sequence in layup, composite structure can exhibit various types of deformation coupling when subjected to loading. In certain applications, such anisotropic behavior can be tailored to benefit specific needs. For example, the bending/twisting coupling has been extensively studied for the purposes of aeroelastic tailoring[3,4]. The application of extension/twisting deformation coupling to the constrained-layer damping treatment was explored in Ref. 2. In Refs. 5 and 6, a new approach of applying extension/twisting deformation coupling to damping treatment was proposed for the axial-type truss member. In this approach, the viscoelastic material is embedded in a structural member made of fiber reinforced composite material. By a judicious tailoring, the structural member can exhibit the extension/twisting deformation coupling such that the viscoelastic material is sheared in twisting while the structural member undergoes an axial deformation.





New Material Concept

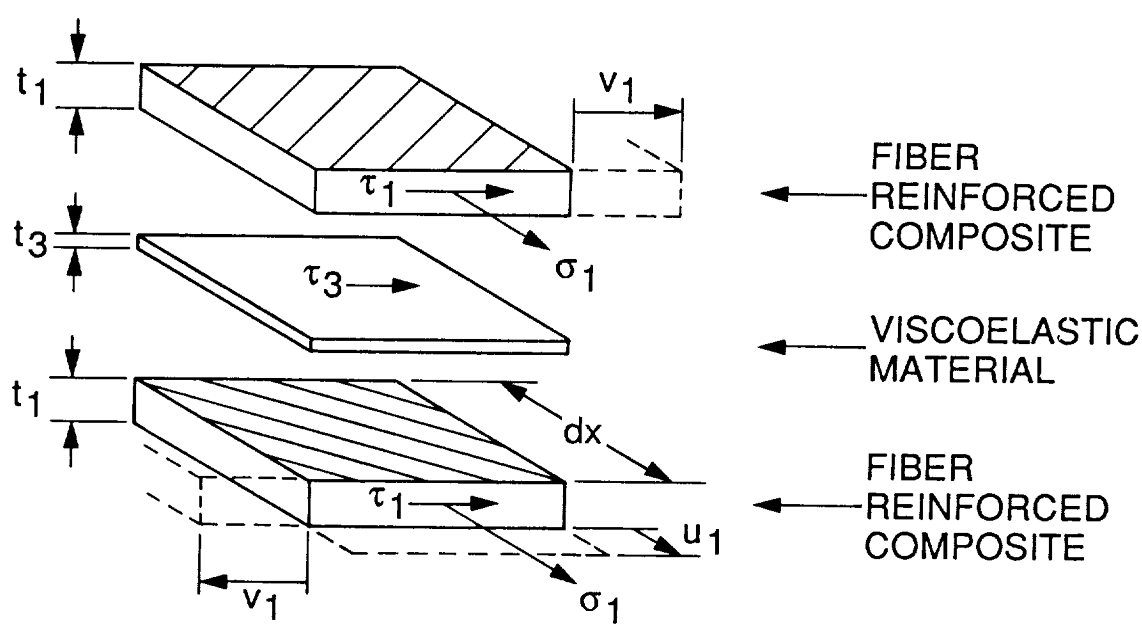
However, the difficulty with this new approach is that it requires a built-in twisting freedom in the truss member. In reality, such added design complexity is usually forbidden. To avoid such undesirable requirement, a new material concept of using saw-toothed (or V-shaped) fiber in reinforced composite was conceived in Ref. 7. With the V-shaped fiber, a truss member is allowed to undergo twisting deformation at knee-points while its both ends remain fixed. Damping performance was studied on a plane strain model as shown below. The resulting shear strain distribution in the viscoelastic material is a hyperbolic sine function along the member axis which is similar to the result of constrained-layer damping treatment[2]. The member loss factor is estimated from the expression of complex stiffness as

$$K_m = K \cdot \left(1 + \mu \cdot \frac{\tanh \sqrt{\beta}}{\sqrt{\beta}} \right) \qquad \eta_m = \frac{\text{Imaginary } (K_m)}{\text{Real } (K_m)}$$

where

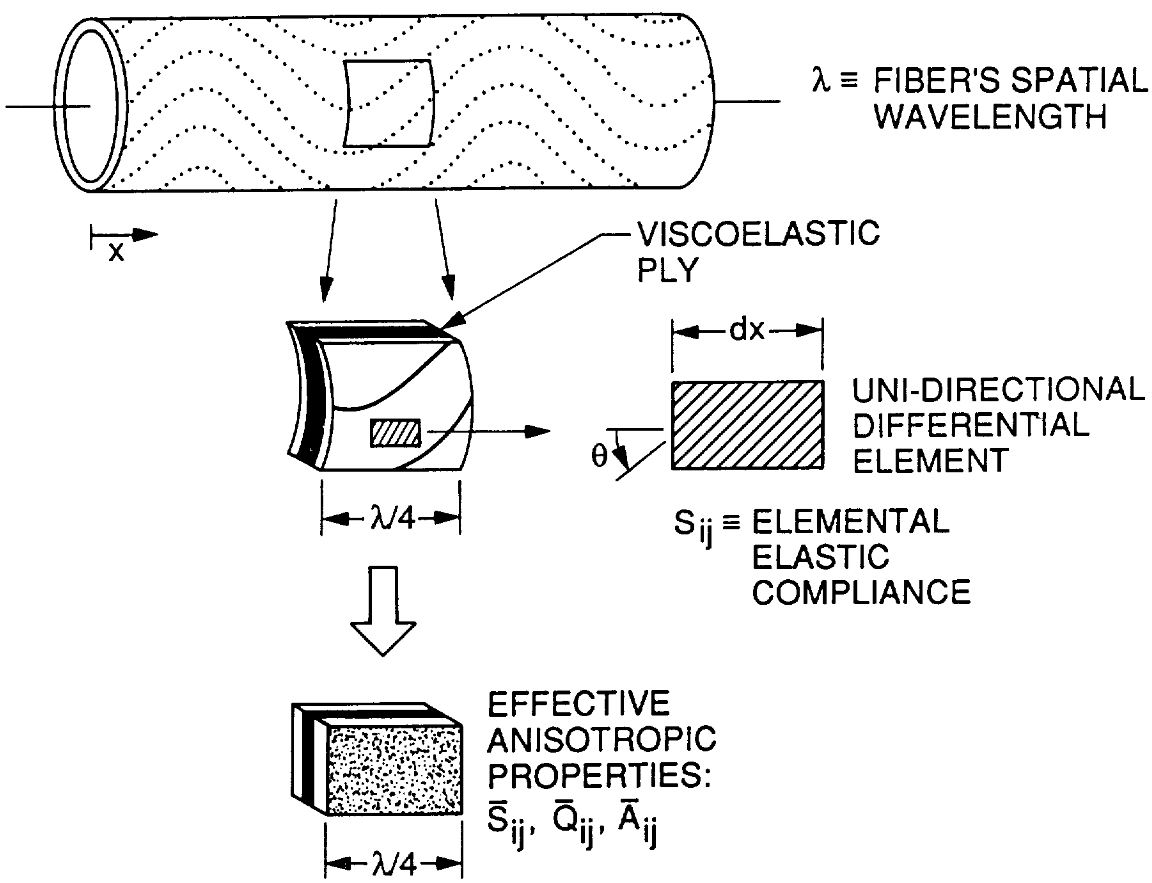
$$\mu = \frac{A_{16}^2}{A_{11}A_{66} - A_{16}^2} \qquad \beta = L^2 \cdot \frac{2G_2}{t_2} \cdot \frac{A_{11}}{A_{11}A_{66} - A_{16}^2}$$

Examining the above expression indicates that the member loss factor is only a function of two parameters. One is the extension/twisting coupling coefficient, μ, which is a function of the composite material properties and its layup. The other is a combined geometry/material parameter, β.



Analysis Model for Waved Fiber Reinforced Composites

The idealized V-shaped fiber is useful in performance trade study. In practice, however, the V-shaped fiber is not really feasible because of its sharp corners. In this investigation, the sine-waved fiber reinforced composite is analyzed for this new damping treatment approach. The analysis model of a truss member made of iso-phased sine-waved fiber reinforced composite is shown below. In this design, the fiber orientation is antisymmetric with respect to the viscoelastic material (VEM) layer, i.e., $[+\theta_n/\mathrm{VEM}/-\theta_n]$ layup, such that the twisting deformation in the viscoelastic material is maximized under axial load. Because of the continuously varying fiber orientation, the truss member's elastic properties are varying along the member axis. In this study, a concept of using equivalent homogeneous model with effective elastic properties is proposed to evaluate the member's damping performance. The effective anisotropic properties are estimated in average sense over one quarter of the fiber's spatial wavelength.



Effective Anisotropic Properties

Spatial dependent strain-stress relation:

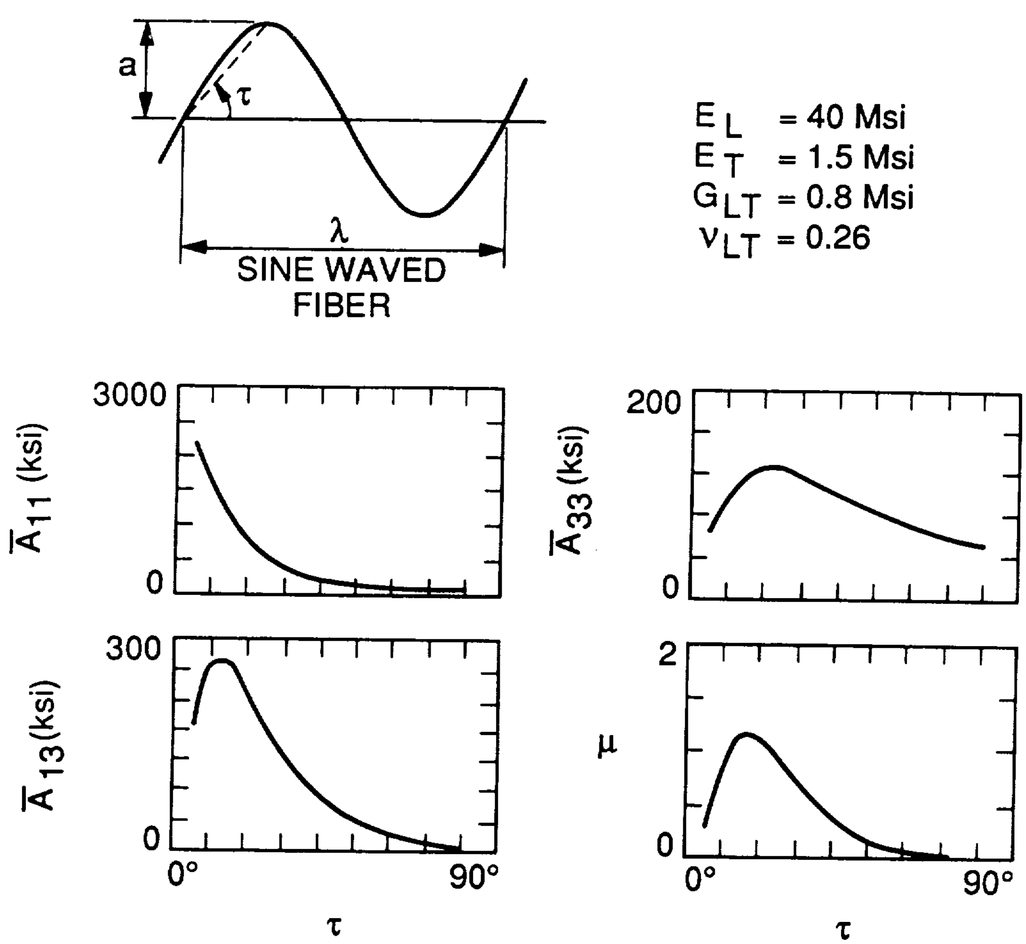
$$\{\epsilon\} = [S(\theta)]\ \{\sigma\}$$

where the S_{ij}'s are the elemental elastic compliance and the tangent fiber orientation, θ, is given by

$$\theta = \tan^{-1}\left[\frac{2\pi a}{\lambda} \cdot \cos(2\pi x/\lambda)\right]$$

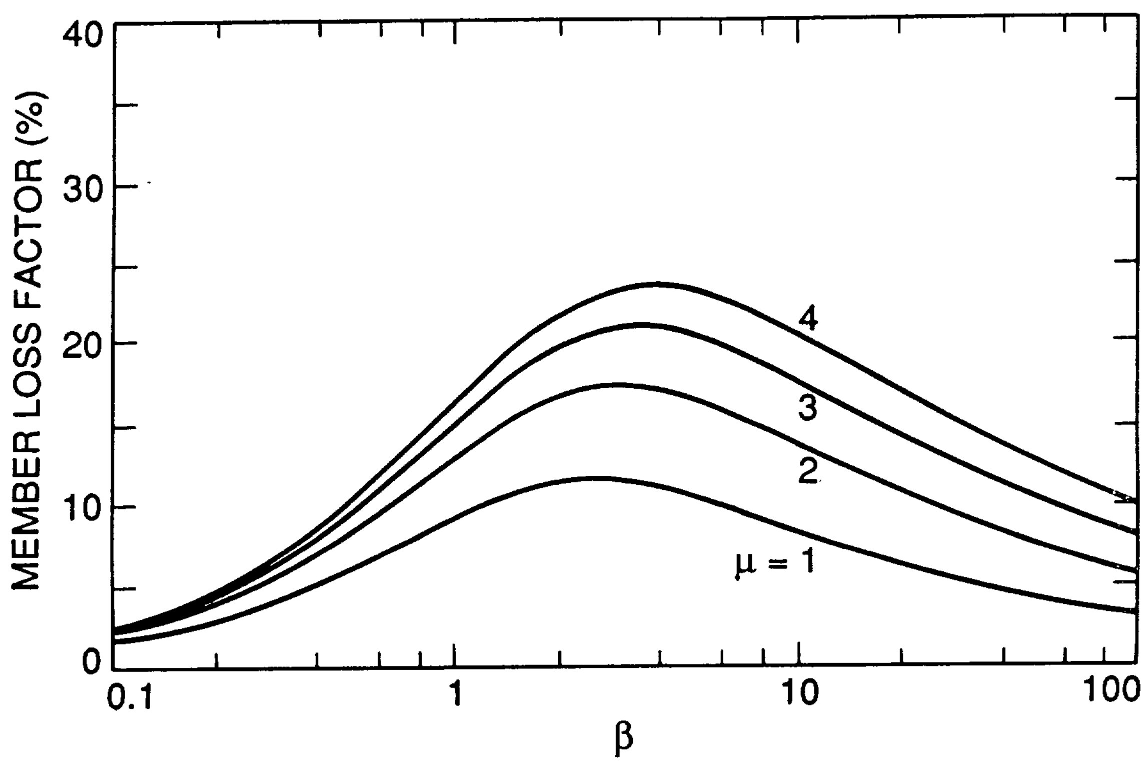
The effective compliance is

$$\bar{S}_{ij} = \frac{1}{\lambda/4} \cdot \int_{o}^{\lambda/4} S_{ij}(x) \cdot dx$$



Examples

Given the material loss factor, $\eta_{vem} = 1.0$, functional dependency of the member loss factor on the extension/twisting coupling coefficient, μ, and parameter β are illustrated in the following example. It is interesting to note that the β_{opt} is not very sensitive to the variation in μ. For the example of HMS/3501-6, $\mu_{opt} = 1.2$ at $\tau = 18^o$, the maximum loss factor attainable is about 17%.



Summary

- New material concepts, i.e., V-shaped and sine-waved fiber reinforced composite materials, were investigated for the new damping treatment in axial-type structural members.

- The underlying mechanism of an elastically tailored damping member depends on the extension/twisting deformation coupling in composite materials. As a result, the embedded viscoelastic material is sheared in twisting when the member undergoes axial motion.

- Shear strain distribution in the viscoelastic material is similar between the extension/twisting coupled damping treatment and the constrained-layer damping treatment.

- A concept of using an equivalent homogeneous model with effective anisotropic properties was proposed to evaluate damping performance of members made of iso-phased sine-waved fiber reinforced composite material.

- Numerical examples show that the sine waved-fiber reduces the degree of extension/twisting deformation coupling as compared with the V-shaped fiber reinforced composite material. However, its effect on the β parameter is less critical because the β parameter can be optimized through other geometric parameters.

- With the optimally selected geometric and material parameters, the attainable loss factor of the elastically tailored damping member ranges from 10-25% which is about in the same performance range of the damping member with constrained-layer damping treatment. The major advantage of the elastically tailored damping member is that there is no additional weight penalty such as the constraining layer of the constrained-layer damping treatment.

References

1. Soovere, J. and Drake, M.L., Aerospace Structures Technology Damping Design Guide, Vol. 2, December, 1985, AFWAL-TR-84-3089.

2. Chen, G-S. and Wada, B.K., "Passive Damping for Space Truss Structures," AIAA SDM Issues of the International Space Station, Williamsburg, VA, April 21, 1988, AIAA Paper 88-2469.

3. Shirk, M.H., Hertz, T.J., and Weisshaar, T.J., "Aeroelastic Tailoring-Theory, Practice, and Promise," Journal of Aircraft, Vol. 23, January, 1986, pp. 6-18.

4. Chen, G-S. and Dugundji, J., "Experimental Aeroelastic Behavior of Forward-Swept Graphite/Epoxy Wings with Rigid-Body Freedom," Journal of Aircraft, Vol. 24, No. 7, July, 1987, pp. 454-462.

5. Barrett, D.J., "A Design for Improving the Structural Damping Properties of Axial Members," Damping Workshop 1989, West Palm Beach, FL, February 8-10, 1989.

6. Dolgin, B.P. and Chen, G-S., "Composite Damping Strut with Viscoelastic Plies," 1989 TMS Fall Meeting, Indianapolis, Indiana, October 1-5, 1989.

7. Dolgin, B.P., "Composite Passive Damping Strut for Large Precision Structures," JPL New Technology Report, NPO-17914, 1989.