

High Damping Hierarchical Composites

Roderic S. Lakes, Professor, PI

Colby C. Swan, Asst. Professor, co-PI

Funding Agency: U.S. NSF

Project Description

The proposed research is directed toward the development of technologies capable of damping vibrations in structures such as those in aircraft and automobiles, over a wide range of temperature. To that end, composite materials of high stiffness and high mechanical damping are to be developed. The principle leading to high performance is structural hierarchy combined with inhomogeneous (non-affine) deformation. Hierarchical solids contain structural elements which themselves have structure. Lessons learned from natural hierarchical high performance materials such as human bone are to be incorporated in the material development. Moreover, lessons from prior successful study of hierarchical strong, lightweight honeycomb are to be incorporated. Results of analytical study are to be used as starting points for a program in topology optimization.

Mechanical properties sought in aerospace engineering material systems include exceptional specific strengths, stiffness, and damping – all to be achieved with competitive economy and high durability. Because such diverse properties often cannot be achieved economically with single-phased metallic material systems, designable composite material systems are being increasingly considered for such applications. The potential advantages of using composites over traditional metallic systems include: weight savings through higher specific stiffnesses and strengths; carefully designed directional properties; reduced part count over metallic equivalents; modified radar response; corrosion resistance in salt environments; excellent fatigue resistance; dimensional stability; and enhanced life cycle economy. Certain classes of composite materials offer the potential of high damping as well as high stiffness. Composites have found their way not only into airplanes but also automobiles, railroad cars, and bridges.

A simplistic *definition of a composite* is an integrated material system that combines two or more constituent phases of different mechanical properties to achieve a new material with enhanced mechanical/transport properties. The effective mechanical properties of composites are determined primarily by the properties of the materials being combined and the spatial/topological arrangement of the phases in the composite at the material structural scale. In designing composites, two fundamental questions must therefore be satisfactorily addressed:

- a. What materials are to be combined, and in what proportions? and
- b. How will these materials be arranged spatially at the material structural scale?

The quantities of stiffness and mechanical damping are to be achieved in a hierarchical composite structure. Structural hierarchy permits structural features on different length scales to perform various roles. Composites with inhomogeneous deformation are chosen since both theoretically and experimentally it has been demonstrated to facilitate the achievement of stiff, high damping composites.

The potential benefit of such materials in vibration abatement is a reduction in damage to aircraft due to vibration and metal fatigue, a reduction in pilot fatigue, reduction in noise which causes discomfort to passengers and flight crew, reduction in disturbances to electronic equipment, and improved performance due to reductions in weight. If cost can be reduced sufficiently, wide applications in automobiles are possible.

Composite materials are to be prepared with structure guided by composite-theoretical analysis of material properties. The first iteration will involve stiff particles of silicon carbide, of multiple length scales, embedded in an indium-tin matrix. Such a configuration has been shown to be promising via analytical study using the correspondence principle. Each level of structural hierarchy corresponds to known manufacturing methods. For example, the first efforts will be based on melt infiltration. Subsequent iterations are to be guided by principles of topology optimization. At the heart of the proposed design method is a robust analysis framework (computational homogenization) that can accurately compute the effective or homogenized mechanical properties associated with arbitrary periodic material structural configurations. Due to its considerable generality, computational homogenization is very amenable to simultaneous analysis and design optimization of broad classes of composite materials. Experimental study of the composite materials is to be conducted using a unique apparatus capable of measurements of viscoelastic properties over more than eleven decades of time and frequency, with no appeal to time-temperature superposition, which in general cannot be used with composite materials.