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Analysis on Mechanical Damping of Composite Materials

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Abstract

The damping capacity of a material is the fundamental property for designing and manufacturing structural components in dynamic applications. Materials with high damping properties are highly desirable to suppress mechanical vibration and transmission of waves, thus decreasing noise and maintaining the stability of structural systems. Experimental and analytical characterization of damping is difficult, with conventional structural materials, and the anisotropic nature of composite materials makes it even more difficult. Fiber-reinforced polymer composites (FRPC) has good properties such as light-weight, high specific strength and stiffness, compared with metals [1–2]. The viscoelastic characteristics of the polymer matrix in FRPC, improves the dynamic stability of the structure. Experimental approaches range from laboratory bench-top methods to portable field inspection techniques, and analytical techniques vary from simple mechanics-of-materials methods to complex three-dimensional finite-element approaches to eliminate vibration.

Introduction

The vibrations are movements of the component itself rather than just internal vibrations of the molecules. Damping is a process in which vibrational energies are converted into some other energy form, usually heat. The two kinds of vibration considered are mechanical vibrations or acoustic vibrations. At the fundamental level, both the vibrations can be treated in a similar way. The objective of this paper is to analyse the effects of vibration on composite structure and the damping effects.

In most cases, vibrations are not desired and it is essential to be controlled by efficient methods. Vibrations can damage the part itself or mechanisms attached to the vibrating part. An example is the airplane part that can break because of vibrations. Vibrations can cause a part to move or to deform. The telescopes are a prime example where this type of vibrations should be avoided to take perfect pictures. Some vibrations results in uncomfortable, if they not controlled. Example for this type of vibration is the vibrations that might be sensed from a driver seat in a car or at the whack of a tennis racket. The amount of damping in a part is dependent on three things, they are: (i) The materials out of which the part is made (ii) The design of the model/experimental prototype and (iii) An element that might be added to the part which could include specific damping treatments and whose effect on damping is more complicated to analyse.

Composites have better damping properties than structural metals. The damping in composites is controlled by the matrix properties, the fiber properties, the interaction between the fibers and the matrix, laminar stacking sequence, and embedded viscoelastic layers. The composite structures are widely used in aerospace applications, where a large strength : weight ratio is required. Similar to isotropic materials, composite materials are subjected to various types of damage, mostly cracks and delamination. This result in local changes of the stiffness of elements for such materials and consequently their dynamic characteristics are altered. Most engineering structures are built up by connecting structural components, because assembled structures need sufficient damping to limit excessive vibrations under dynamic loads. Damping in such structures mainly originates from two sources. One is the internal or material damping which is inherently low [1] and the other one is the structural damping due to joints [2].

The structural damping is an excellent source of energy dissipation, thereby adequately compensating towards the low material damping of structures. But, this is only in the case of metallic structures and not in composites. It is estimated that metallic structures consisting of bolted or riveted members contribute about 90% of the damping through the joints. The internal damping or material damping in case of composites is generally more, when compared to material damping in metallic structures. Often, damping in composites starts when the best damped metal stops. For this reason, damping in composites is of recent interest and many researches are being done.

The three essential parameters that determine the dynamic responses of a structure and its sound transmission characteristics are mass, stiffness and damping. Mass and stiffness are associated with storage of energy. Damping results in the dissipation of energy by a vibration system. For a linear system, if the forcing frequency is the same as the natural frequency of the system, the response is very large and can easily cause dangerous consequences. In the frequency domain, the response near the natural frequency is "damping controlled". Higher damping can help to reduce the amplitude at resonance of structures. Increased damping also results in faster decay of free vibration, reduced dynamic stresses, lower structural response to sound, and increased sound transmission loss above the critical frequency.

Literature Survey

ASME published a collection of papers on structural damping in 1959 [6]. Lazan's book published in 1968 gave a very good review on damping research work, discussed different mechanisms and forms of damping, and studied damping at both the microscopic and macroscopic levels [7]. Lazan conducted comprehensive studies into the general nature of material damping and presented that the logarithmic decrement values increase with dynamic stress, i.e., with vibration amplitude, where material damping is the dominant mechanism. Nashif, Jones and Henderson published another comprehensive book on vibration damping [8]. Jones wrote a handbook especially on viscoelastic damping 15 years later [9]. Sun and Lu's book published in 1995 presents recent research accomplishments on vibration damping in beams, plates, rings, and shells [10]. Finite element models on damping treatment are also summarized in this book.

Damping in vibrating mechanical systems has been subdivided into two classes: Material damping and system damping, depending on the main routes of energy dissipation. Coulomb (1784) postulated that material damping arises due to interfacial friction between the grain boundaries of the material under dynamic condition. Further studies on material damping have been made by Robertson and Yorgiadis (1946), Demer (1956), Lazan (1968) and Birchak (1977). System damping arises from slip and other boundary shear effects at mating surfaces, interfaces or joints between distinguishable parts. Murty (1971) established that the energy dissipated at the support is very small compared to material damping.

Bert [14] and Nashif et al. [15] had done survey on the damping capacity of Fiber reinforced composites and found out that composite materials generally exhibit higher damping than structural metallic materials. Chandra et al. [16] has done research on damping in Fiber-reinforced composite materials. Composite damping mechanisms and methodology applicable to damping analysis is described and had presented damping studies involving macro-mechanical, micromechanical and Viscoelastic approaches. Gibson et al. [17,18] and Sun et al. [18,19] assumed viscoelasticity to describe the behaviour of material damping of composites. The concept of specific damping capacity (SDC) was adopted in the damped vibration analysis by Adams and his co-workers [20-21], Morison [22] and Kinra et al [23].

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Lin et al. [21] predicted SDC in composites under flexural vibration using finite element method based on modal strain energy (MSE) method considering only two inter laminar stresses and neglecting transverse stress. Koo KN et al. [32] studied the effects of transverse shear deformation on the modal loss factors as well as the natural frequencies of composite laminated plates by using the finite element method based on the shear deformable plate theory. Singh S. P. et al. [31] analysed damped free vibrations of composite shells using a first order shear deformation theory in which one assumes a uniform distribution of the transverse shear across the thickness, compensated with a correction factor.

Polymeric materials are widely used for sound and vibration damping. One of the more notable properties of these materials, besides the high damping ability, is the strong frequency dependence of dynamic properties; both the dynamic modulus of elasticity and the damping characterized by the loss factor [30-35]. Mycklestad [34] was one of the pioneering scientists into the investigation of complex modulus behaviour of viscoelastic materials (Jones, 2001, Sun, 1995). Viscoelastic material properties are generally modeled in the complex domain because of the nature of visco-elasticity.

Viscoelastic materials possess both elastic and viscous properties. The typical behaviour is that the dynamic modulus increases monotonically with the increase of frequency and the loss factor exhibits a wide peak [8, 33]. It is rare that the loss factor peak, plotted against logarithmic frequency, is symmetrical with respect to the peak maximum, especially if a wide frequency range is considered. The experiments usually reveal that the peak broadens at high frequencies. In addition to this, the experimental data on some polymeric damping materials at very high frequencies, far from the peak centre, show that the loss factor–frequency curve flattens and seems to approach a limit value, while the dynamic modulus exhibits a weak monotonic increase at these frequencies [34-38]. These phenomena can be seen in the experimental data published by Madigosky and Lee [36]. The computerized methods of acoustical and vibration calculus require the mathematical form of frequency dependences of dynamic properties. A reasonable method of describing the frequency dependences is to find a good material model fitting the experimental data.

Conclusion

In recent years, there has been increased interest in high dielectric constant flexible particulate composites composed of a ferroelectric ceramic and polymer for high density energy storage and capacitor applications [39]. Usually, the dielectric constant of such polymer based composites is rather low (about 50) because of the lower dielectric constant of the matrix (usually below 10) [39, 40]. For instance, in BaTiO3/epoxy composites, with high dielectric constant (>1000), the effective dielectric constant (εeff) of the composite was as low as 50, even when the highest possible concentration of ceramics was incorporated [40] with the concentration of ceramics increases and the composite loses its flexibility.

A new generation of high dielectric materials such as barium zirconium titanate ceramics (BZT) can be used in order to obtain composites with better performance. A number of theoretical studies and experimental observations have attempted to elucidate the remarkable (high) dielectric properties of BZT material. The interest in high strain piezoelectric materials increases for electromechanical transducers and various related applications [41]. Although the large family of lead-based perovskites and relaxors has shown great potential, lead-free compositions in these families will be of interest due to obvious future environmental concerns. Modified Ba(Zr,Ti)O3 has shown systematic changes in dielectric, piezoelectric, and phase transition characteristics in the bulk ceramic and single crystal forms [42]. In the paraelectric state, just above *Tc*, BZT ceramics are prefferred for dynamic random access memories and tunable dielectric devices. Ba(Ti0.9Zr0.10)O3 powders (BZT) were employed to produce the composite material because it has improved dielectric and ferroelectric properties [43]. Epoxy resins are being widely used in industrial applications such as adhesives and matrices for composite materials. High performances must be achieved through the synthesis and processing of the materials; in particular, good mechanical behavior, stiffness and toughness, is expected.

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