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Review

Analytical and empirical modeling of multilayered elastomeric isolators from damping experiments

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ABSTRACT

Experimental studies have been performed on elastomeric layered composites to characterize the nonlinearity in dynamic stiffness and specific damping energy, so that their performance can be enhanced as isolators. The present study is divided into two parts: (a) analytical modeling of isolator samples, and (b) formulation for glue characteristics. Several samples of layered arrangement of elastomer and metal strips were used in the experiments. Dynamic and static loading experiments were performed. All these experimental results were used in developing nonlinear empirical models for the elastomer characteristics. Furthermore creep–fatigue test was performed to explain certain observed behavior in the elastomer characteristics. Concluding part of the paper discusses empirical formulation of the layered sample considering elastomer and adhesive layers as basic elements, thus evolving a method to calculate adhesive properties.

Contents

1. Introduction

Unwanted vibrations can raise hazardous conditions in any type of dynamic system ranging from large multi-bladed helicopters to small electronic component systems. Consequently vibration control has been a point of concern for engineers to improve system performance. Viscoelastic materials, often termed as amorphous or elastomeric polymers, are extensively used as means to mitigating resonant vibration responses, by providing damping in the structure. A very common approach is to use pads or sheets, made of elastomeric polymer, between the base and the movable component and this is commercially known as vibration isolator. The sheets or layers of elastomer can be modified with sandwiched metal layer, giving rise to layered composites, with flexibility of shape ranging from mat, tube, bar or even very tiny isolators.

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An excellent example, towards the application of layered elastomers, is in their incorporation in helicopter rotor blades as dampers to provide requisite stiffness and suitable damping. In the design of these elastomeric dampers, it is always crucial to meet the geometric constraints of size of these dampers. Before one attempts to address the inverse problem of designing the elastomer with specific dimensions for required stiffness and damping, it is essential to develop an analytical model for multi layer elastomers which is first validated with experimental data. Therefore the development of an analytical model is of significant importance, in the design of multi-layered elastomer for engineering applications. The objective of present study is to develop suitable analytical model for the behavior of elastomer under dynamic loading condition, based on the dynamic experiments performed on multi-layer elastomers. The present study not only addresses the analytical modeling of elastomers, it also addresses the influence of adhesive layer on the overall performance of the elastomer.

In general vibration damping can be incorporated in two ways, namely, active approach or by passive scheme [1]. In active vibration method, materials such as piezoelectric and piezoceramic are incorporated into a composite solid producing smart structures with in-built sensing and actuation capabilities using external power source, to counteract vibration forces [2]. While passive vibration control uses viscoelastic property of the material which dissipates energy during deformation. In this study, the characterization of viscoelastic material is discussed due to their low cost and availability.

Under dynamic loading, the viscoelastic materials exhibit certain behavior which is typically characterized as neither a pure solid nor a pure liquid. For example, when sinusoidal stress is applied to such material, the strain is neither exactly in-phase (solid) nor 90° out-of-phase (liquid), but is somewhere in between. Some amount of input energy is stored and recovered in each cycle, while some amount of energy is dissipated as heat. The reason for this behavior of these materials is attributed to the complicated molecular arrangements, with continuously changing gross long-range contours [3]. Under external stress, these contours rearrange rapidly in local scale, while the rearrangement rate is slow in larger scale [4,5]. These materials due to the presence of chemical constituents of different configurations like monomers, chain structure, and chemical stereoregularity etc. execute nonlinearity in fundamental properties with varying external thermo-mechanical or chemical conditions [6]. Extensive work in the field of nonlinearity related to damping factors are documented in Refs. [4,5] and very recently by Bird et al. [7]. Constitutive equations were developed for individual material, using different mathematical models and experimental set-ups [4,8,9].

Two key components regulating damping capacity of any material including elastomers are loss tangent (denoted by $\tan\delta$), and storage modulus E_s. Loss tangent is a quantitative measure of damping capacity or the heat dissipated by the material per loading cycle, while storage modulus provides an idea about the stiffness capacity. Product of these two elements is termed as loss modulus E_l, a measure of damping in terms of energy. While complex modulus denoted by E^* is defined as the overall measure of dynamic mechanical response of the element upon loading, and is mathematically denoted by the vector summation of storage and loss module.

With improvements in technology, several instruments have been developed in past few decades to measure the dynamic properties of polymers. However, each equipment has its own limitations of material usage and working conditions [4,10,11]. In the present study, the equipment *MetraviB DMA*+100 is used to measure the dynamic response of the isolator samples under harmonic loading. Mechanical hysteresis loop is generated by plotting instantaneous force versus deformation over a cycle [12,13]. Analytical model is developed by correlating loading force with deformation and rate of deformation.

It is known that viscoelastic materials exhibit creep behavior under constant load. Hence it is important to understand how the creep behavior affects the fatigue characteristics of the elastomer which is used as damper element. To observe the creep–fatigue behavior of the material, the sample is tested under stress being held constant at peak compressive stress, with fatigue cycle under strain control [14]. The Creep–Fatigue (CF) hysteresis loop obtained presents an idea for overall variation in shape of the sample at different time intervals.

It is well known that property of layered sample is much dependent on the quality of the adhesive used. Thus it should be possible to improve the isolator performance by experimentally knowing the property of the adhesive. An adhesive sample of desired dimension is prepared and experiments were conducted to obtain its dynamic properties. Following the approach given in Refs. [15,16], a new formulation of the empirical formulae for the physical properties of the layered sample is proposed by treating both adhesive and elastomer layers as constitutive elements. It is shown in this study that the proposed empirical formulae provide a good agreement with experimental data.

2. Experimental set-up

Dynamic mechanical analysis (DMA) is a measurement technique derived from the field of rheology, which deals with the study of the deformation and flow of materials due to the application of oscillatory force. This technique provides information about various other transitions of materials along with major transitions, which are not readily identified by other methods [17]. These information with fair degree of mathematical calculations, produce desired constituent equation for the elastomer sample discussed in this paper.

Several samples having different dimensions were prepared with different combinations of natural elastomer and metal (aluminum) layers glued together with adhesives. A separate adhesive sample was also prepared, by allowing the adhesive to dry for a prolonged period, to test the property of the adhesive material. Dimensions of the test samples were decided according to the DMA manual [18] and are discussed in Table 1. The dimensions and the lay-up of the samples are given in Table 1. For conciseness, certain nomenclatures are used, when metal layers are placed in the samples. For example