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ON REMARKABLE LOSS AMPLIFICATION MECHANISM IN SANDWICH PANELS WITH COMPOSITE FACE SHEETS REINFORCED WITH COATED FIBERS

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1. INTRODUCTION

Effective vibrational and noise control structures are important in aerospace and automotive industry. Less vibrational energy leads to longer life of components and structures while less noise means comfort to passengers as well as to surrounding environments. In aerospace industry, the requirement for high vibrational damping and high strength/stiffness composites now seems to be mandatory especially when more aircraft structural components are designed with reinforced polymer-matrix composite materials. As a result, various design optimizations to improve both damping and stiffness properties of composite structure have been proposed in the frame of micromechanics and structural mechanics [1, 2]. In the present work, we concern ourselves with traditional way of optimizing dynamic properties of sandwich panels but solution is addressed from the nanotechnology perspective where an ultra-thin coating layer of viscoelastic material on the reinforced fibers in the composite face sheets is considered. With this optimization, a remarkable high loss amplification effect can be observed on the levels of lamina, laminate and sandwich panel structure with such composite face sheets.

Reinforced polymer composite material, apart from its high strength and stiffness to weight ratio characteristic, is naturally a good damping material. In such composite, polymer-matrix is the source of damping mechanism [2]. The contribution of inclusions to damping can be very significant when high volume fraction of inclusions is present. In general, a comparably higher or the same level of damping as the matrix can be obtained for composite structure that has inclusions, about hundred times stiffer than the matrix [3]. To further increase damping capacity of composite, a hybrid concept of combining composite and viscoelastic material is examined. With viscoelastic composite material, good combination of high damping and high stiffness properties might be achievable [4]. In the last decade, various authors have investigated this hybrid concept analytically and numerically [3-10]. At micromechanical level, their basic strategy is to have viscoelastic lossy layer coated between stiffer phases [6, 7], while at macromechanical level, viscoelastic layer is selectively placed between sheets or laminates [8]. Nevertheless, the results showed that although higher damping capacity of composite is obtainable, retaining sufficiently high stiffness is proved difficult [1, 5].

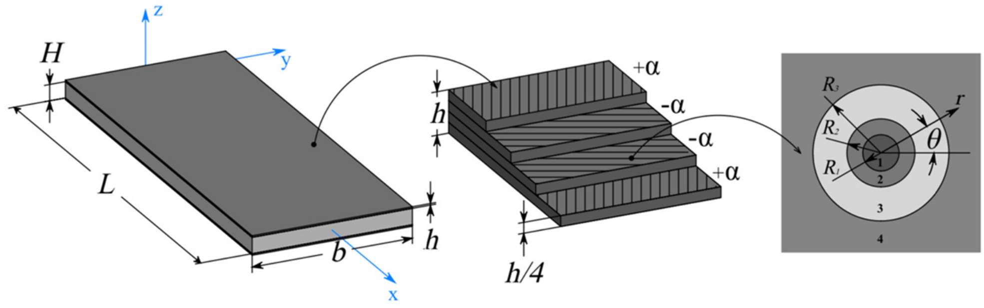
Searching for optimum balance between loss and stiffness, Gusev and Lurie [7] examined the effect of thickness of viscoelastic coating layer surrounding spherical inclusions that are embedded in epoxy matrix system. It is found that at extremely thin coating layer, the effective shear loss modulus of composite increases substantially. At the same time, the decrease in its effective storage modulus is minimal. This high loss amplification effect is so extreme that its effective loss modulus value significantly exceeds the loss moduli of constituents in the composite. Later the similar effects was found in fiber reinforced composites [8] and in wavy layered composites [9] containing ultra-thin viscoelastic layers. Clearly, this approach of optimization shows that high loss and high stiffness composite structure might be attainable, and this is due to the presence of high shearing damping mechanism in viscoelastic layer [4, 7, 9].

In the present work, we provide a further development of the proposed strategy for the increase of damping and stiffness properties for the sandwich panels which composite face sheets reinforced with coated fibers. Overall stiffness and damping properties of the foam filled panels are examined by the analytic and numerical means. Rational design method is proposed. Optimal values of microscopic and macroscopic parameters of considered composite structures are found. It is shown the significant influence of the ultra-thin viscoelastic coatings on the overall properties of the panels.

2. MODELLING METHODOLOGY AND RESULTS

We consider a flat sandwich panel with polyurethane foam core and with face sheet that consists of epoxy matrix reinforced with coated glass fibers. Coating is made of rubber-toughened epoxy with improved damping behavior. All materials except the fibers are assumed to be viscoelastic, and their behavior is described by frequency-dependent complex moduli. To analyze micromechanical behavior of lamina, we use a micromechanical model of coated cylindrical inclusion. Generalized self-consistent method with elastic-viscoelastic correspondence principle are involved in the analytical estimations (Fig. 1(c)). Classical theory of laminates is involved to study the mechanical performance of face sheets with symmetric angle-ply lay-up (Fig. 1(b)). First-order shear deformation analysis of simply-supported sandwich plates is performed to investigate the overall properties of sandwich structures under consideration (Fig. 1(a)). Using proposed multiscale analytical model an optimal set of the model parameters (coating thickness, fiber volume fraction, lamination angle of face sheets, core thickness) are found for the best damping behavior of sandwich plate. Fundamental modal loss factor of the panel is considered as the target function in maximization problem.

Numerical verification for the obtained optimal sandwich structure is given. We consider a sandwich panel model with solid second order hexahedral elements for the core layer and with Mindlin-Reissner plate elements for the faces. In the finite-element modeling we use the frequency dependent storage modules and loss factors of the face plates material found from preliminary micromechanical analysis. Viscoelastic properties of the core are taken from known experimental data. Vibrational behavior of the panel is simulated in frequency domain using frequency/harmonic response analysis in the Femap/Nastran system. We consider a lateral vibrations of simply-supported panel with prescribed harmonically varying displacements of supported ends. Based on numerical solution we found a frequency response function for the panel vibrations amplitude and estimate the modal loss factor of the panel based on "half-power" method. Comparison between obtain finite element and analytical predictions allows us to check the accuracy of the last one as well as to check the significance of longitudinal and rotatory inertia effects, high order shear effects in the core etc. that are neglected in the analytical model.



(a) *(b)* *(c)*

Fig. 1: Modeling scheme. (a) Three-layer sandwich panel, (b) four-layer laminated face plates with a symmetric angle-ply lay-up, (c) model of a coated cylindrical inclusion in the framework of the generalized self-consistent method (1 - fiber, 2 - coating, 3 - matrix, 4 - equivalent homogeneous medium)

Analytical and numerical study reveals that at ultra-thin coating layer, the laminas exhibits very high loss characteristics where its effective loss moduli significantly exceed the loss moduli of both coating and matrix materials (Fig. 2). High shearing dissipation mechanism in ultra-thin layer of viscoelastic coating material is found to be responsible for this peculiar behavior. This remarkable loss amplification effect is technologically appealing as such composites with high damping and high stiffness properties might be attainable. From Fig. 2, it is clear that both effective transverse Young's and shear loss moduli (E_T, G_T) have two distinct peaks. One of the peaks, as before occurs at extremely thin coating layer. Here, the possibilities of obtaining enhanced composite's damping capacity while maintaining sufficiently high stiffness characteristic can be observed. In this case, the loss moduli increase more than 10 times, and the decrease in stiffness is between 15 and 20 % only. These effects are studied then at the laminate and sandwich structure levels. It is found a strong relation between overall damping properties of the sandwich panel and parameters of the microscopic viscoelastic coatings.

Analytical design methodology is proposed to find optimal values of micromechanical and structural parameters of the model to provide a highest stiffness and damping behavior of the panels. Example of the panel fundamental modal loss factor estimation for different coating thicknesses (micro parameter) and lamination angles (macro parameter) are given in Fig. 3. It is found that a balance between the damping improvement and the stiffness decrease can be achieved by using thin viscoelastic coatings, a lamination angle close to $\alpha = 20^\circ$–30° and a sufficiently thick core. The panel with the maximum loss factor is realized with a [±45] lay-up. For the considered panels with glass-fiber-reinforced epoxy face plates and polyurethane cores, it is shown that the application of thin rubber-toughened epoxy coatings to the fibers should allow one to increase the fundamental modal loss factor of a panel by a factor of greater than ten. The optimal relative coating thickness for the fibers is approximately 0.1 times the fiber radius. For a typical glass fiber radius (5-10 μm), this means that the coating thickness should be approximately 0.5-1 μm.

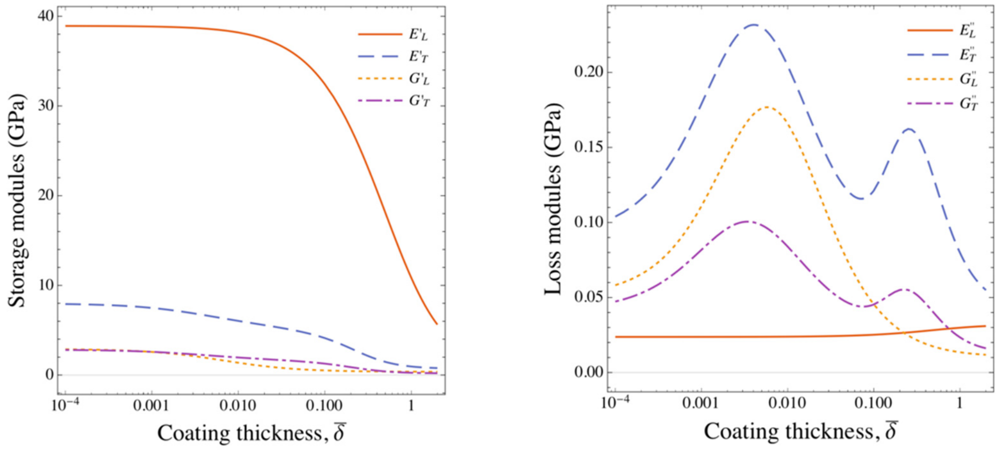
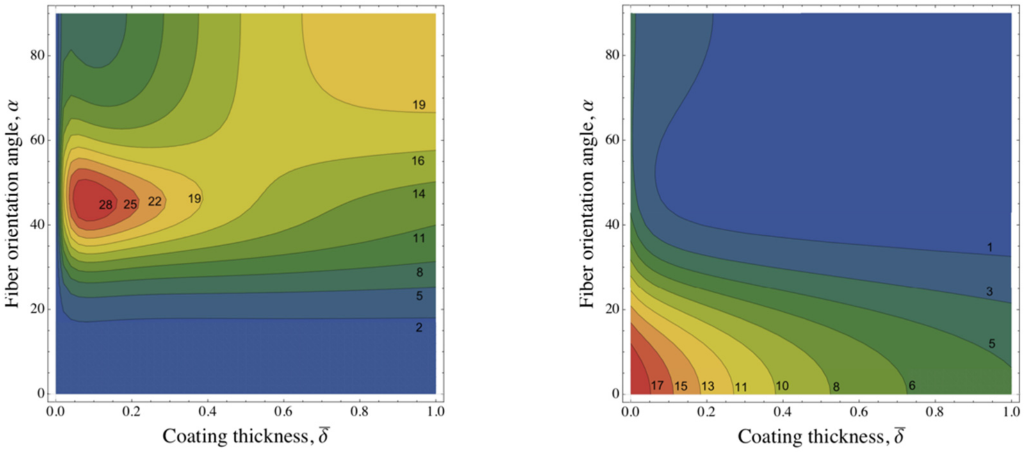


Fig. 2: Effective storage and loss moduli of the lamina vs. relative coating thickness (divided on the fibers radius).



(a) ***(b)***

Fig. 3: Sandwich panel properties vs. coating thickness and lamination angle. (a) Fundamental modal loss factor, (%); (b) bending stiffness per unit width, (10^3 Nm); property values are shown by colors and labels on the contours.

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