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Low-velocity impact response of active thin-walled hybrid composite structures embedded with SMA wires

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Abstract

Effect of some important parameters on low-velocity impact response of the active thin-walled hybrid composite plates embedded with the shape memory alloy (SMA) wires is investigated in this paper. The interaction between the impactor and the composite plate is considered in the impact analysis. The SMA wires are embedded within the layers of the composite laminate. The effect of the SMA wires on contact force history, deflection, in-plane strains and stresses of the structure was studied. The first-order shear deformation theory as well as the Fourier series method is utilized to solve the governing equations of the composite plate analytically. The interaction between the impactor and the plate is modeled with the help of two degrees-of-freedom system, consisting of springs-masses. The Choi's linearized Hertzian contact model is used in the impact analysis of the laminated hybrid composite plate. The results indicate that some of the important geometrical and physical parameters like the SMA volume fraction, orientation of composite medium fibers, impactor mass, impactor velocity, and length-to-thickness ratio of the plate (a/h ratio) are important factors affecting the impact process and the design of structures.

Keywords: Impact; Thin-walled; Composite; Shape memory; Low velocity

1. Introduction

Bulk shape memory alloys present temperature and strain sensing properties, as well as striking actuation properties in terms of strain or recovery stress, which make them smart materials, albeit only in a restricted sense with limited applications. To increase their application range as smart structural materials, one needs to combine these alloys produced in the form of wires or ribbons with a host structural material. Composite materials containing embedded SMA wires are now reaching the point where they can be manufactured at a laboratory or prototype scale with good reproducibility and the desired properties for simple configurations. Progress is still needed to design complex structures and ensure long-term reliability. These materials have been the center of attention recently.

Abrate [1–3] studied the impact behavior of composite laminates extensively. Olsson [4–6] classified low-velocity impacts in two categories, known as the small mass and the large-mass impact. This classification is based on the ratio of impactor mass to the target (here hybrid composite plate) mass. Small impactor masses cause a small mass response dominated by shear and flexural waves in which the load, deflection, and flexural strains are out of phase. Impactor masses much larger than the laminate mass would cause a 'quasi-static' large mass response, in which the peak load, deflection, in-plane strains and stresses are more or less in phase.

Sun and Chen [7] examined the positive effect of tensile stresses to improve the impact resistance of the composite materials. Active energy tuning is the one of the ways to increase the impact resistance of the structures [8]. In this method, the prestrained SMA wires are embedded in the layers of a traditional multilayered composite structure. If the temperature of the wires is increased, they transform to austenite phase and tend to contract.

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If this contraction is prevented, positive recovery tensile stresses are generated which improve the impact damage resistance of the structure. Birman et al. [9] demonstrated that if the SMA wires were embedded inside the traditional polymer composites, these tensile stresses could be generated inside the structures. Hence, the impact resistance of the structures would be increased. They also demonstrated that if some SMA wires were embedded inside different layers of the structure, the global deflection of the structure would be reduced in low velocity impacts. They used constitutive relationship and associated micromechanics for a hybrid SMA composite material, which were considered in a number of studies [10,11]. In addition, some of the researchers [11–13] verified the above theories by experiments. Roh et al. [14,15] embedded the SMA wires inside a traditional multilayered laminated composite structure and utilized the energy balance and the FEM method to study the effect of the same parameters worked in Birman's article [9].

In the present research, a complete model was developed so that the effect of low velocity impact upon the multilayered laminated smart composite plates was demonstrated. The effect of using SMA wires as well as some of the parameters such as the volume fraction of the SMA wires, the mass and the velocity of the impactor in a constant energy level, the orientation of composite medium fibers and the length-to-thickness ratio of the composite plate (a/h ratio) on the impact response of smart hybrid composite plate is studied in details.

2. Governing equations

The plate equations developed by Whitney and Pagano [16] are used as they included the effect of transverse shear deformations. The assumed displacement field is

$$
\begin{aligned}
u &= u^0(x,y,t) + z\psi_x(x,y,t),\\
v &= v^0(x,y,t) + z\psi_y(x,y,t),\\
w &= w^0(x,y,t),
\end{aligned} \tag{1}
$$

where u^0, v^0 and w^0 are the plate displacements in x, y and z directions at the plate mid-plane and ψ_x and ψ_y are the shear rotations in the x and y directions. Reducing the equation to specially orthotropic form ($B_{ij}=0$, $A_{16}=A_{26}=D_{16}=D_{26}=0$), and adding the uniform in-plane initial stress resultants N^i_x and N^i_y as discussed by Sun and Chattopadhayay [17] results in

$$
\begin{aligned}
&D_{11}\psi_{x,xx} + D_{66}\psi_{x,yy} + (D_{12}+D_{66})\psi_{y,xy}\\
&\quad - k_{sh}A_{55}\psi_x - k_{sh}A_{55}w_{,x} = I\ddot{\psi}_x,\\
&(D_{12}+\mathrm{D}_{66})\psi_{x,xy} + D_{66}\psi_{y,xx} + D_{22}\psi_{y,yy}\\
&\quad - k_{sh}A_{44}\psi_y - k_{sh}A_{44}w_{,y} = I\ddot{\psi}_y,\\
&k_{sh}\mathrm{A}_{55}\psi_{x,x} + (k_{sh}A_{55}+N^i_x)w_{,xx}\\
&\quad + k_{sh}A_{44}\psi_{y,y} + (k_{sh}A_{44}+N^i_y)w_{,yy} + q = \rho\,\ddot{w}
\end{aligned} \tag{2}
$$

k_{sh} is the shear correction factor introduced by Mindlin [18], normally taken to be $\pi^2/12$. In addition, q is the dynamic normal load (transverse impact) over the plate and

$$
(A_{ij}, B_{ij}, D_{ij}) = \int_{-h/2}^{h/2} Q^k_{ij}(1, z, z^2)\,\mathrm{d}z,
$$
$$
(\rho, I) = \int_{-h/2}^{h/2} \rho_0\left(1, z^2\right)\mathrm{d}z. \tag{3}
$$

In the above relation, ρ_0 represents the density of each layer and ρ is the total density of the plate. In addition, I is the moment of inertia and h is the thickness of the plate. Q_{ij}

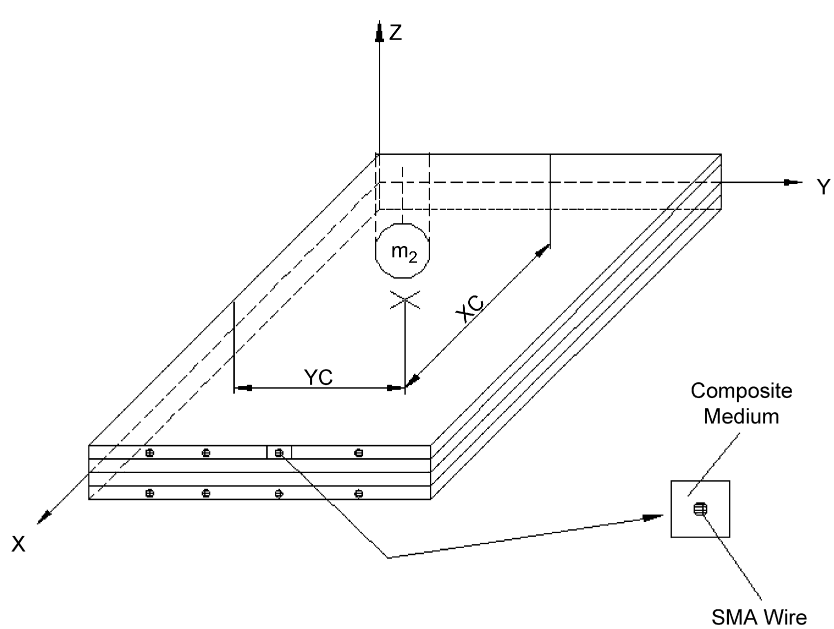

Fig. 1. Schematic view of the SMA hybrid composite plate impacted by a spherical mass.