STUDY ON THE RESPONSE TO LOW-VELOCITY IMPACT OF A COMPOSITE PLATE IMPROVED BY SHAPE MEMORY ALLOY

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ABSTRACT Improvement from the pseudo-elastic effect of shape memory alloy (SMA) on the low-velocity impact (LVI) resistance of a composite plate is investigated by the finite element method (FEM). The stiffness matrix of the dynamic finite element equation is established step by step and the martensite fraction is obtained at each time step. The direct Newmark integration method is employed in solving the dynamic finite element equation, while the impact contact force is determined using the modified Hertz's law. It is found that SMA can effectively improve the performance of a composite structure subjected to low-velocity impact. Numerical results show that the deflection of a SMA-hybrid composite plate has been reduced approximately by thirty percent when the volume fraction of the embedded SMA reaches 0.3.

KEY WORDS shape memory alloy, composite plate, low-velocity impact, FEM

I. INTRODUCTION

It is well known that composite materials have advanced characteristics such as high strength-to-weight ratio, high stiffness-to-weight ratio, and the capability of flexible design and fabrication. They are extensively applied in military and civil engineering. However, composite structures are vulnerable to low-velocity impact (LVI), which may result in extensive delamination and multiple matrix cracking. The presence of such internal damages will reduce the strength of composite structures to fifty percent, and even lead the structures to collapse [1]. Thus, research on the impact response of composite structures has gained much attention in recent years [8]. There is an increasing demand for improving the low-velocity impact response property of composite structures.

The applications of shape memory alloy (SMA) are very wide owing to their unique shape memory and pseudo-elastic effects. It has been proved by experiment that an effective way to reduce the delamination caused by LVI is to embed some pseudo-elastic SMA fibers in the composites. Many researchers have been studying this topic in recent years. Paine and Rogers [2] investigated the LVI response of SMA reinforced composite beam experimentally. Their experimental results show that the impact-resistance property of the composite materials can be increased significantly. Birman et al. [3] studied the global deformations of SMA reinforced composite plates subjected to LVI, and found that the deflection of
A composite plate improved with SMA can be reduced approximately by one-third that of the same plate without SMA improvement.

So far, most of the research on impact response of SMA-hybrid composites has carried out by experiment method. In the present paper, we examine effects of SMA on the LVI resistance of a composite plate. Numerical results show that the pseudo-elastic behavior of SMA produces great improvement on the LVI property of a SMA-hybrid composite plate.

II. THE CONSTITUTIVE RELATIONS OF SMA-HYBRID COMPOSITE PLATE

The SMA embedded into the composite plate is in the form of fibers as shown in Fig.1.

The one-dimensional constitutive relation of SMA without the thermal elastic effect is given by

$$\sigma = E_S(\xi)\varepsilon + \Omega(\xi)\xi_S$$

where \(\xi = \xi_S + \xi_T\) is the martensite fraction, \(\xi_S\) and \(\xi_T\) are the martensite fractions induced by stress and temperature, respectively, \(\Omega\) is the transformation tensor of SMA, and \(E_S\) is the Young’s modulus of SMA given by

$$E_S = E_A + \xi(E_M - E_A)$$

where \(E_A\) and \(E_M\) are Young’s moduli of austenite and martensite, respectively.

For \(\sigma_s^{\alpha} + C_M(T - M_s) < \sigma < \sigma_f^{\alpha} + C_M(T - M_s)\) and \(T > M_s\), the martensite fraction is

$$\xi = \frac{1}{2} \left\{ 1 + \cos \left[ \frac{\pi}{\sigma_s^{\alpha} - \sigma_f^{\alpha}} \left[ \sigma - \sigma_f^{\alpha} - C_M(T - M_s) \right] \right] \right\}$$

where \(\sigma_s^{\alpha}\), \(\sigma_f^{\alpha}\) are the critical stresses at the start and end instants of the martensitic transformation, respectively. \(T\) is the temperature, \(C_M\) the transformation constant and \(M_s\) the starting temperature of the martensitic transformation.

Assume that the SMA-hybrid composite plate is transversely isotropic, its material coefficients can be calculated as follows:

$$(E_1, \nu_{12}) = (E_{m1}, \nu_{m12})V_m + (E_S, \nu_S)V_f, \quad (E_2, G_{12}) = \frac{(E_{m2}E_S, G_{m12}G_S)}{(E_{m2}, G_{m12})V_f + (E_S, G_S)V_m}$$

where \(E_1\), \(E_2\), \(\nu_{12}\) and \(G_{12}\) are the elastic moduli, the Poisson’s ratio and the shear modulus of the SMA-hybrid composite plate; \(E_{m1}\), \(E_{m2}\), \(\nu_{m12}\) and \(G_{m12}\) the elastic moduli, the Poisson’s ratio and the shear modulus of the matrix; \(\nu_S\) and \(G_S\) the Poisson’s ratio and the shear modulus of SMA; \(V_m\) and \(V_f\) the volume fractions of the matrix and the SMA fibers, respectively.

The constitutive relation of the SMA-hybrid composite plate is formulated as

$$\sigma = C\varepsilon$$