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Simulation of constrained layered damped laminated plates subjected to low-velocity impact using a quasi-static method

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ABSTRACT

This investigation presents a quasi-static simulation method that adopts energy conservation and the results from the static crush to simulate the impact behavior of carbon-epoxy composite laminate plates. These plates consist of adhered visco-elastic material, and formed constrained layered damped (CLD) components. The damping force is considered in the quasi-static simulation. Comparison with experimental results indicates that the proposed method yields accurate results and produces significant saving in computing resources.

1. Introduction

Carbon fiber reinforced plastic (CFRP) has been adopted widely because of its light, high stiffness and high strength. CFRP material is brittle, and absorbs little energy in impact loading. Hence, the impact strength of CFRP is always considered before applying it to structure construction. Finite element method (FEM) software has been used in many investigations, [1,2]. The failure of composite material is a very complex issue, involving time-consuming simulation of dynamic behavior. Belingardi and Vadori [3] therefore, studied the mechanics of GFRP plate under low-velocity impact by ASTM. However, FEM simulations or experiments are always very time-consuming and expensive. Results of low-velocity experiments indicate that the failure forms of static crush and low-velocity impact are very close. Therefore, this study adopts the quasi-static algorithm to simulate the CFRP with constrained layered damping (CLD) under low-velocity to obtain dynamic impact results quickly.

The quasi-static method has been applied to simulate the low-velocity impact for many years. Huang and Lee [4,5] established a quasi-static simulation rule for CFRP plates and shells. Under the low-velocity impact, the force–displacement (F–s) curve of static crush can be utilized to simulate the impact behavior of different impactor masses and impact velocities. This study considers the constrained layered damped effects using constrained layered damping (CLD) based on visco-elastic damping and aluminum. A sandwich-like plate is formed by adhering CLD to a laminated plate. The impact strength of sandwich plate is always concerned with the core. For the CLD laminated plate, the core is visco-elastic and excellent shear-deformation ability can be employed to dissipate the impact energy constantly.

FRP sandwich plates subjected to impact have been widely discussed recently. For instance, Fatt and Park [6] adopted different dynamic models to predict the low-velocity impact response of sandwich panels under different boundary conditions. Gustin et al. [7] experimentally investigated the low-velocity impact characteristics of a sandwich CFRP plate with a honeycomb core. Jiang and Shu [8] considered the local displacement of the core in a two-layer sandwich composite plate subjected to low-velocity impact. Malekzadeh et al. [9] utilized the three degree of freedom (TDOF) mass-spring-damping model to simulate the responses of composite panels with transversely flexible core subjected to low-velocity.

This study discusses the use of quasi-static methods to simulate the impact response of CFRP laminated plate with CLD and considers the damping force during the impact. Finally, the quasi-static simulation results are compared experimentally, confirming the accuracy of the quasi-static method with damping. Experimental and quasi-static simulation results of this study could serve as the basis for discussing the low-velocity impact behavior of laminate plate with CLD specimens.

2. Quasi-static method for laminate plate with CLD

This study applies the quasi-static method. The impact energy is assumed to be absorbed by the elastic deformation and fracture of laminate plate with CLD component. The impactor can thus be considered as a signal system, and the dynamic energy variation of the impactor equals the energy absorbed by the laminate plate.

The damping c and stiffness k of the signal-degree-of-freedom system are addressed. The impactor mass is m, the initial velocity is v_0, and the velocity variation during the impact is $v(t)$. The damping force F_d can thus be expressed as $F_d = cv(t)$. Fig. 1 illustrates the

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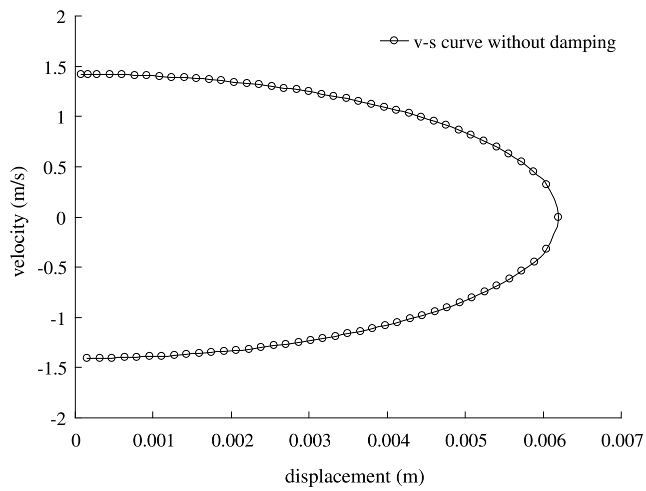

Fig. 1. Velocity–displacement curve subjected to low-velocity impact without damping.

relationship between impact velocity v and displacement s (v–s) as defined by Huang and Lee [4]. If the v–s trend of CLD laminate plate is similar to that without damping in Fig. 1, then the relationship between damping force $F_d = cv$ and displacement s is as given in Fig. 2(b).

The energy conservation during the impact is considered. Assuming the dynamic energy lost from the impactor all transferred the work of mass-spring-damping system. The equation can be expressed as:

$$\frac{1}{2}m[v_0^2 - v^2(t)] = \int_0^s F\mathrm{d}s + \int_0^s F_d\mathrm{d}s \tag{1}$$

Fig. 2 shows F–s and F_d–s curves, after obtaining the force–displacement (F–s) curve of static crush. The impact energy of the first displacement increment s_1 can be expressed as Eq. (2).

$$W_1 = W_{k1} + W_{d1} = \frac{1}{2}F_1 s_1 + \frac{1}{2}c(v_0 + v_1(t))s_1 = \frac{1}{2}m[v_0^2 - v_1^2(t)] \tag{2}$$

The velocity of the first step, $v_1(t)$, can be computed by solving Eq. (2).

$$v_1(t) = \frac{-cs_1 \pm \sqrt{(cs_1)^2 - 4mF_1 s_1 + 4m^2 v_0^2 - 4mcv_0 s_1}}{2m} \tag{3}$$

The damping force $F_{d1} = cv_1(t)$ and energy W_1 of the first increment can all be obtained once $v_1(t)$ is known.

The energy corresponding to the next displacement increment s_2 can thus be written as Eq. (4).

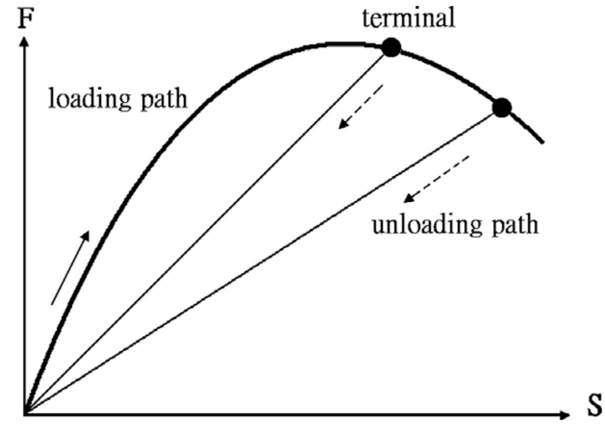

Fig. 3. Integration path and unloading path.

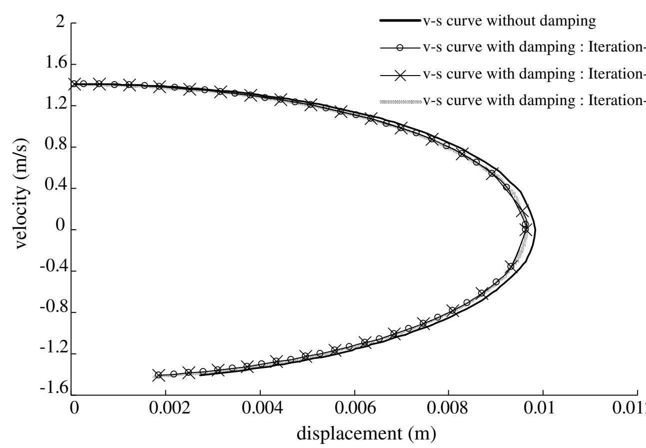

Fig. 4. The v–s trends after iteration.

$$\begin{aligned} W_2 &= W_1 + [(F_2 + F_1) \times (s_2 - s_1)/2] + [c(v_2(t) + v_1) \times (s_2 - s_1)/2] \\ &= \frac{1}{2}m[v_0^2 - v_2^2(t)] \end{aligned} \tag{4}$$

By solving Eq. (4), the velocity of the second increment, $v_2(t)$, can be expressed as Eq. (5).

$$\begin{aligned} v_2(t) = &-\frac{c}{2m}(s_2 - s_1) \\ &\pm \sqrt{\left[\frac{c}{2m}(s_2 - s_1)\right]^2 - \frac{2}{m}\left[W_1 + \frac{s_2 - s_1}{2}(F_1 + F_2 + cv_1) - \frac{1}{2}mv_0^2\right]} \end{aligned} \tag{5}$$

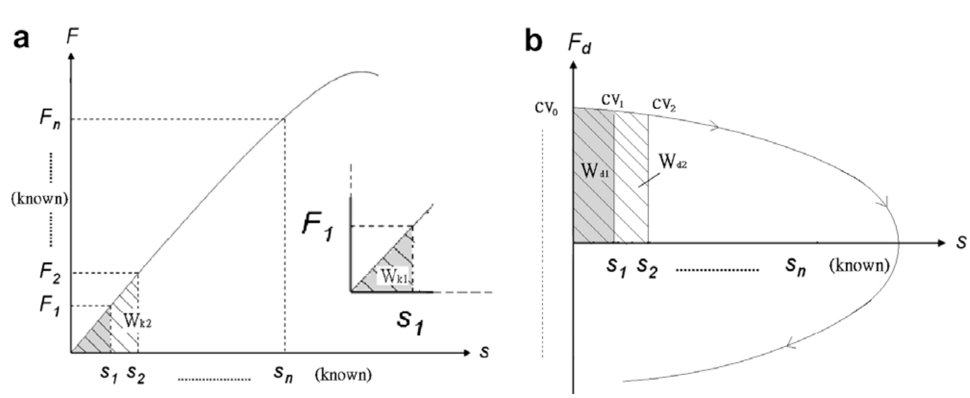

Fig. 2. Static crush F–s curve and F_d–s curve.