IMPACT RESPONSE AND DAMAGE ANALYSIS OF IN-PLANE LOADED COMPOSITE LAMINATES

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INTRODUCTION

A few studies on impact behaviour of composite laminates under in-plane load have been published [1]. In 1985, Chen and Sun [2] had developed a finite element program to analyze impact response of composite laminate under biaxial in-plane load. They concluded that initial tensile in-plane load tends to intensify the contact force while reduce the contact time, and an opposite conclusion is obtained for initial compressive in-plane load. After their study, it is very rare to find another analytical result on impact behaviour of composite laminates under in-plane load. Kelkar and Sankar etc. [3] reported an experimental and analytical result on impact response and damage area through drop-weight type impact test. In the study, it was observed that as the initial in-plane load increases, in the case of 16 ply laminates the damage area increased. However, in the case of 32 ply thick laminates, there was only a marginal increase in it. In the case of 48 ply thick laminates, for lower impact energy there was also a marginal increase in it, however for larger impact energy there was a decrease. Mashall etc. [4] presented experimental results on impact behaviour of E-glass/polyester composite. They concluded that as the initial tensile in-plane load increases, the contact duration and specimen deflection decreases, however the tensile in-plane load has not affected the maximum contact force and damage area.

From upper references, it can be seen that there is a need for more analytical research on the effect of initial in-plane load on impact behaviour of composite laminates in order to fundamentally understand characteristics of the experimentally observed various phenomena. In this study, a finite element equation based on the modified displacement field was induced to solve structural behaviour of composite laminates under an initial in-plane load. After coding the finite element equation, impact response was numerically analyzed using the finite element program and the numerical output was compared with those from the reference [2]. Also the result was compared with another numerical one under the different impact condition that mass of impactor is very large and impact velocity is very low. Also, in this study, impact damage area was approximately estimated with some assumptions based on the author’s past research experiences [5, 6]. For the present approximate estimation, the complex concept including a new failure criterion for delamination estimation, in-situ strength based on matrix crack onset analysis and test, thermal residual strain by curing and geometrical nonlinear analysis etc. as well as maximum strain value during contact duration should be introduced.

FINITE ELEMENT FORMULATION

Displacement field of plate is modified to consider the initial in-plane strain, ε_{x0}, ε_{y0}, γ_{xy0}.

$$\begin{aligned}
u(x,y,t) &= \varepsilon_{x0}x + \frac{1}{2}\gamma_{xy0}y + u_0(x,y,t) + z\,\psi_x(x,y,t) \\
v(x,y,t) &= \frac{1}{2}\gamma_{xy0}x + \varepsilon_{y0}y + v_0(x,y,t) + z\,\psi_y(x,y,t) \qquad (1) \\
w(x,y,t) &= w_0(x,y,t)
\end{aligned}$$

Applying large deflection theory and Hamilton's principle, finally the following finite element equation on the structural behaviour of plate under in-plane strain can be induced.

$$[M]\{\ddot{U}\}+\left[[K_L]_0+[K_L]+\left[K_N(U)\right]\right]\{U\}=\{F\}+\{F\}_0 \qquad (2)$$

In Eq. (2), describing the physical meaning of $[K_L]_0$ and $\{F\}_0$ related terms with initial in-plane load, a part of the effect of the initial in-plane load is acted as stiffening the plate in its deflection and the other is acted as forcing the plate in in-plane displacement and interlaminar shear deformation.

RESULTS AND CONCLUSION

Typical numerical results in this study are shown in Fig. 1 and Fig. 2. Fig. 1 shows the contact force histories under various initial in-plane loads. It can be seen that the initial in-plane tensile load induces fast response of contact force and the compressive load induces slow response, and the maximum contact forces are similar to each other even under various initial in-plane load conditions. Fig. 2 shows the approximately predicted damage areas (inner closed curves) under various initial in-plane loads. It can be seen that the initial in-plane compressive load induces a little bit larger size of damage area; however the differences between those are almost negligible.

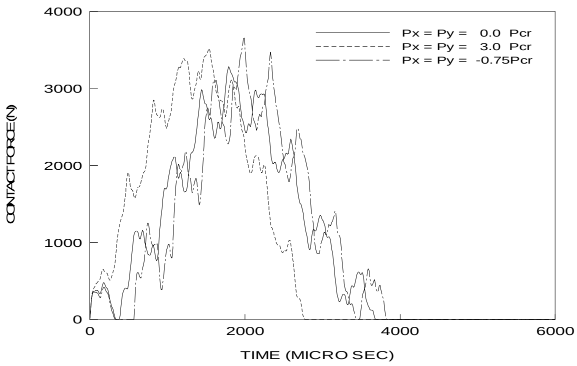

Fig. 1: The contact force histories under various initial in-plane loads.

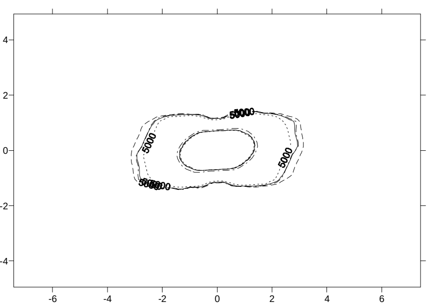

Fig. 2: The approximately predicted damage areas. (Px=Py= 0Pcr : solid, Px=Py= -0.75Pcr : dot-dashed, Px=Py= 0.75Pcr : dashed, Px=-Py= 0.75Pcr : dotted)

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