Uniaxial crushing of cellular sandwich plates under air blast

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Sandwich plates with cellular metal cores are being widely considered for blast mitigation applications, due largely to the energy absorption capacity of the cellular core material. Computational simulations have shown that sandwich plates exhibit reduced deflections relative to solid plates with the same total mass. However, there has been some uncertainty regarding the effect of the thickness of the face sheet nearest the blast, because two competing effects are at work. On the one hand, reducing the thickness of the face sheet means that the blast impulse is imparted to a smaller mass, resulting in increased kinetic energy, which must be dissipated through crushing of the core. On the other hand, reducing the face sheet thickness enhances the beneficial effects of fluid-structure interaction (FSI), which leads to reductions in the impulse imparted to the system. A recent study that accounted for nonlinear compressibility effects in air blast loading on freestanding solid plates found such impulse reductions due to FSI could be fairly significant (Kambouchev et al. 2006). Kambouchev et al. (2006) obtained an approximation that relates the incident and reflected impulses, accounting for nonlinear compressibility and FSI effects, and Vaziri and Hutchinson (2007) presented an approximation for applying this result to sandwich plates.

This presentation will summarize results of an ongoing investigation into the influence of mass distribution on the uniaxial crushing of sandwich plates under air blast, accounting for the effects of nonlinear compressibility and FSI. The analytical model shown in Fig. 1 is considered, in which the cellular core material is represented using the rigid-perfectly plastic-locking (RPPL) idealization, and the solid front and back faces are idealized as rigid. This analytical model has been shown to yield good agreement with explicit finite element computations. An exponential reflected pressure pulse $p_r(t) = p_R e^{-t/t_R}$ is applied to the front face of the sandwich plate, and the approximation of Kambouchev et al. (2006) is used to relate the reflected pressure pulse to the incident pressure pulse $p_i(t) = p_0 e^{-t/t_0}$.

Figs 2a,b show contours with varying mass distribution of the nondimensional reflected impulse I_R and the nondimensional incident impulse I_0 required to produce complete compaction of the core, where

$$I_R = \frac{i_R}{m}\sqrt{\frac{\rho_0}{\sigma_P \varepsilon_D}} \quad \text{and} \quad I_0 = \frac{i_0}{m}\sqrt{\frac{\rho_0}{\sigma_P \varepsilon_D}}$$

in which $m = m_1 + \rho_0 \ell_0 + m_2$ is the total areal density of the sandwich plate, ρ_0 and ℓ_0 are the uncompressed density and thickness of the cellular core, and m_1 and m_2 are the areal densities of the front and back faces. The plateau stress σ_P and densification strain ε_D are shown in Fig. 1b, and $i_R = p_R t_R$ and $i_0 = p_0 t_0$ are the reflected and incident impulse/area. The following symbols, which are used in the ordinate and abscissa of the contours in Fig. 2 and 3, denote the mass fractions in the core and in the front and back faces:

$$\eta_0 = \rho_0 \ell_0 / m ; \ \eta_1 = m_1 / m ; \ \eta_2 = m_2 / m$$

Fig. 2b illustrates an interesting result of the present study, that there are certain mass distributions for which complete compaction of the core cannot be achieved, even if the incident pressure pulse is sustained indefinitely ($I_0 \to \infty$). This is the case in the shaded region of Fig. 2b, which corresponds to a large mass fraction in the core and/or a small mass fraction in the front face. A potentially beneficial function of the cellular core is to limit the accelerations experienced by the back-face of the sandwich plate (e.g., for protection of electronic components). In such an application, it may be of interest to specify a maximum permissible acceleration for the back face, and an associated design optimization problem can be posed by seeking to maximize the impulse that can be sustained while limiting the back-face accelerations to a specified level. A nondimensional back-face acceleration can be defined as $\tilde{a}_2 = (m/\sigma_P)\ddot{u}_2$, and Figs. 3a,b show contours of the maximum allowable values of I_R and I_0 with back-face accelerations limited to $\tilde{a}_2^{max} = 5$. As in Fig. 2b, the shaded region along the upper and left edges of Fig. 3b corresponds to sandwich designs for which the maximum permissible back-face acceleration is not exceeded even if the incident pressure pulse is sustained indefinitely ($I_0 \to \infty$).
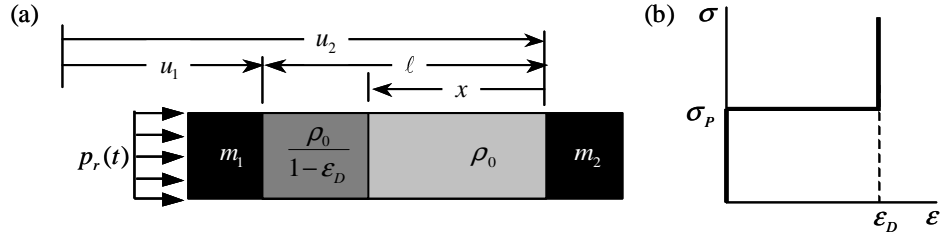
Fig. 1. Analytical model definition. (a) Strip of sandwich panel with partially compacted core; (b) engineering stress-strain relationship for RPPL core material.
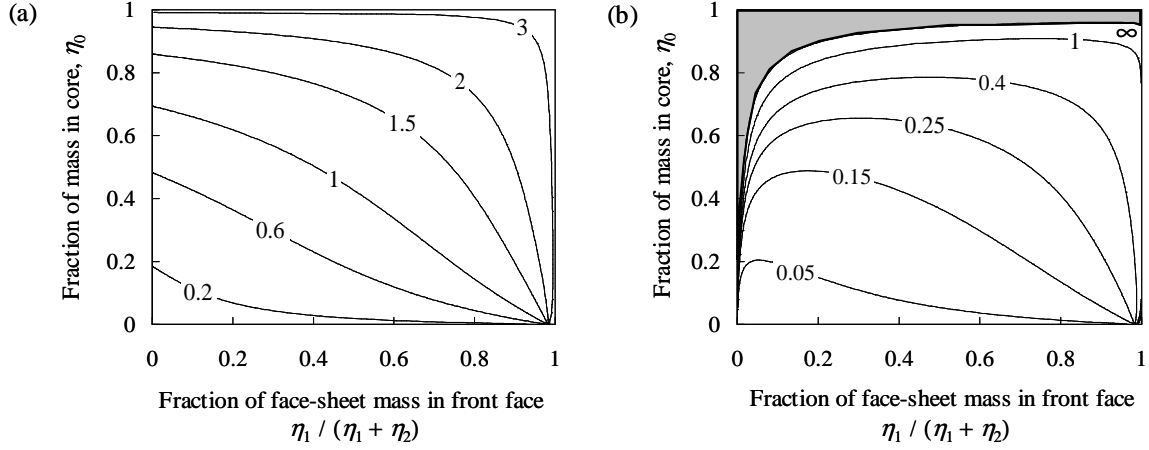

Fig. 2. Contours with varying mass distribution of (a) nondimensional reflected impulse I_R and (b) nondimensional incident impulse I_0 required for complete densification of core ($p_R / \sigma_P = 100$).
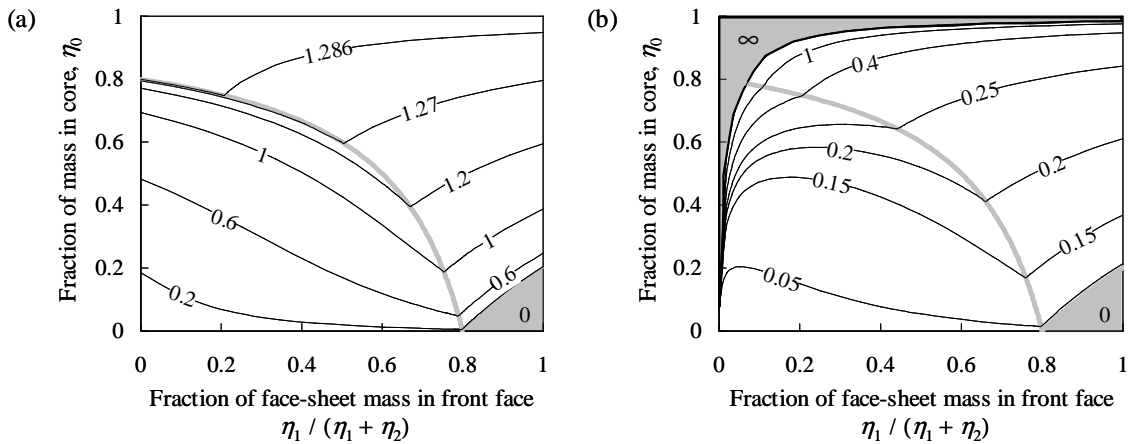

Fig. 3. Contours with varying mass distribution of (a) maximum allowable nondimensional reflected impulse I_R and (b) maximum allowable nondimensional incident impulse I_0 with nondimensional back-face accelerations limited to $\tilde{a}_2^{\max} = 5$ ($p_R / \sigma_P = 100$).

References

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Vaziri, A., Hutchinson, J.W., 2007. Metal sandwich plates subject to intense air shocks. Int. J. Solids and Structures, 44(6), 2021-2035.