BUCKLING AND CRUSHING OF EXPANDED HONEYCOMB

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Summary Commonly used hexagonal honeycomb is manufactured by cold expansion of a laminate of thin metal foils that are bonded along periodically placed strips. This paper evaluates the effect of the expansion on the response of the honeycomb to lateral compression. The expansion is simulated numerically and the resultant honeycomb is compressed laterally. It first buckles, and then collapses by progressive folding. The results are compared to corresponding ones from an ideal, stress free hexagonal honeycomb.

Metallic hexagonal honeycomb remains the most commonly used core in high performance sandwich construction because of its favorable specific stiffness, strength, outstanding energy absorption, and ease of manufacture. The out of plane elastic and inelastic properties, including buckling and crushing by lateral compression, have been widely studied by analytical and numerical models assuming perfectly hexagonal cell geometry that is stress free and using virgin material properties (e.g., [1]). Most commonly used metallic hexagonal honeycomb is manufactured by expanding laminated thin metal foils, which are first bonded along periodically placed strips [2]. The laminate is mechanically expanded producing approximately hexagonal cells with double walls in one direction due to the bonding. The process introduces changes to the inelastic mechanical properties of the foil, leaves behind residual stresses, and some rounding of the bent corners. The aim of this study is to assess the effects of the honeycomb manufacturing process on the calculated properties. To this end we first simulate numerically the expansion process of the Al-5052-H39 honeycomb tested and analyzed in [1]. It has a cell size (c) of 0.375 in (9.53 mm), a wall thickness (t) of 0.00374 in (95 μm) and a height (h) of 0.625 in (15.9 mm), dimensions that lead to a relative density (ρ^*/ρ) of 0.026.

A full height representative cell of periodically bonded stacking of foils [2] assigned the required periodicities and the elasto-plastic characteristics of the material is discretized with 8316 S4 shell elements in ABAQUS/Standard. The domain is mechanically expanded producing the stress-displacement response and configurations ⓪-⑤ shown in Fig. 1 (σ_{ex} ≡ force/final area). The cell is unloaded from a point that results in the desired cell width, c. The process replicates the rounding of the corners, alters the mechanical properties, and leaves behind residual stresses.

The expanded cell with the prehistory locked in is subsequently loaded laterally between rigid planes by prescribing incrementally the relative displacement between the planes, δ. The early part of a typical calculated compressive stress-displacement ($\sigma - \delta/h$) response is shown in Fig. 2, where stress is the force divided by the projected area of the cell. The response is very similar to the corresponding ideal, stress free case in [1]. The plate-like cell walls buckle elastically into a mode that is symmetric about the mid-height (see ① in Fig. 2b; marked on the extrapolated trivial response –dashed line– is the much higher stress level that the honeycomb material would yield). With further compression, the buckled shell starts to lose stiffness due to yielding leading to a stress maximum that represents the strength of the honeycomb. Deformation starts to localize symmetrically at mid-height as shown in ②. The effects of various problem parameters such as the discretization and the size of the domain analyzed are examined and compared to corresponding ideal honeycomb results. Generally, the expansion process lowers both the buckling and collapse stresses by amounts that are less than 10%.

The subsequent crushing that involves progressive folding and contact between the collapsing walls of the cell is performed using ABAQUS/Explicit, again prescribing the displacement δ. A “smooth step” time function is utilized to prescribe δ in order to minimize inertial effects so as to mimic the quasi-static crushing experiments (computation time is 3.6 s). A typical calculated crushing response and three deformed configurations are shown in Fig. 3. Interestingly, unlike the analysis of a stress free honeycomb, imperfection is not necessary to initiate the localization in such a calculation. Configuration ① shows the first fold fully developed at mid-span. As the crushed walls come into contact, the cell regains stiffness and the response picks up again. Subsequently, a new stress maximum and a second fold develop as shown in ②. Contact of the walls limits local deformation, stiffens the structure again, and leads to a third fold shown in ③. Folding continues until the whole cell is crushed. The paper will discuss differences and similarities between crushing responses of expanded and ideal honeycomb models.

References

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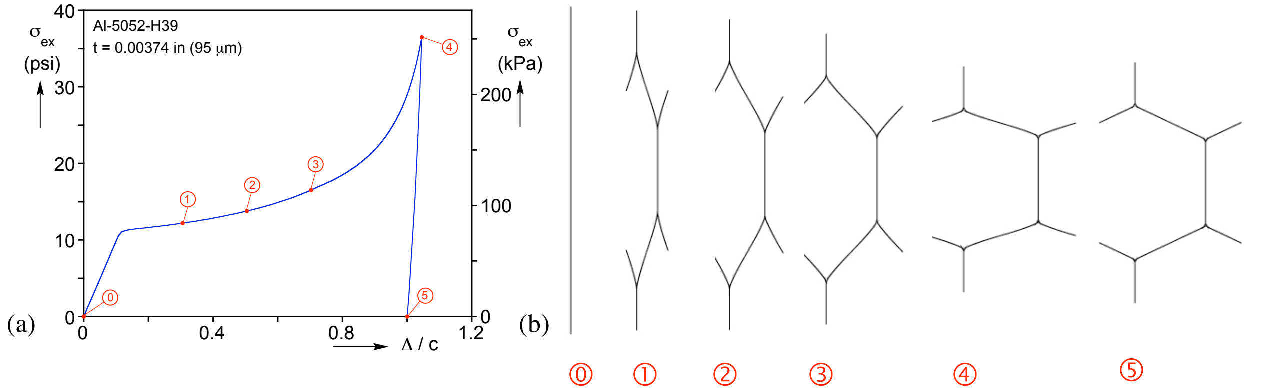

Fig. 1 Expansion of a characteristic cell: (a) stress-displacement response and (b) sequence of deformed configurations.

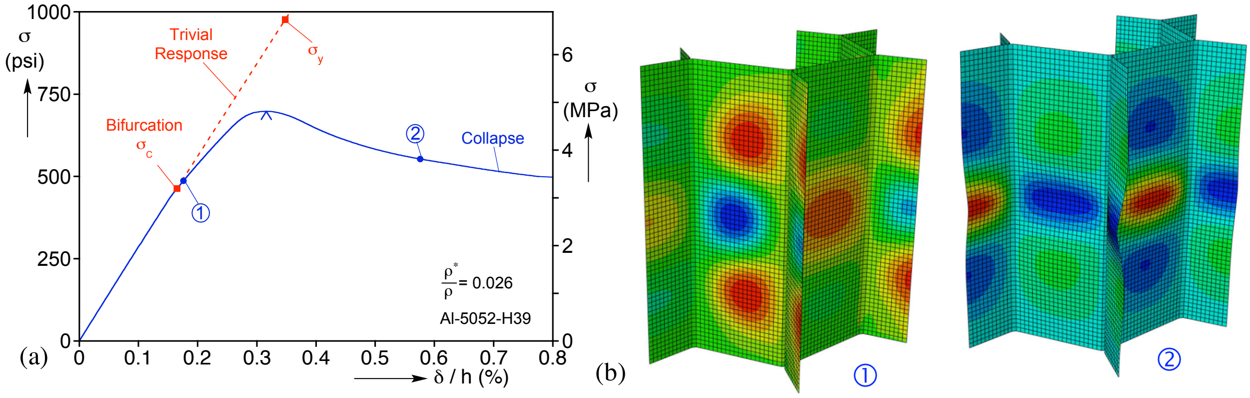

Fig. 2 (a) Initial compressive stress-displacement response of expanded honeycomb and (b) buckled and collapsing configurations.

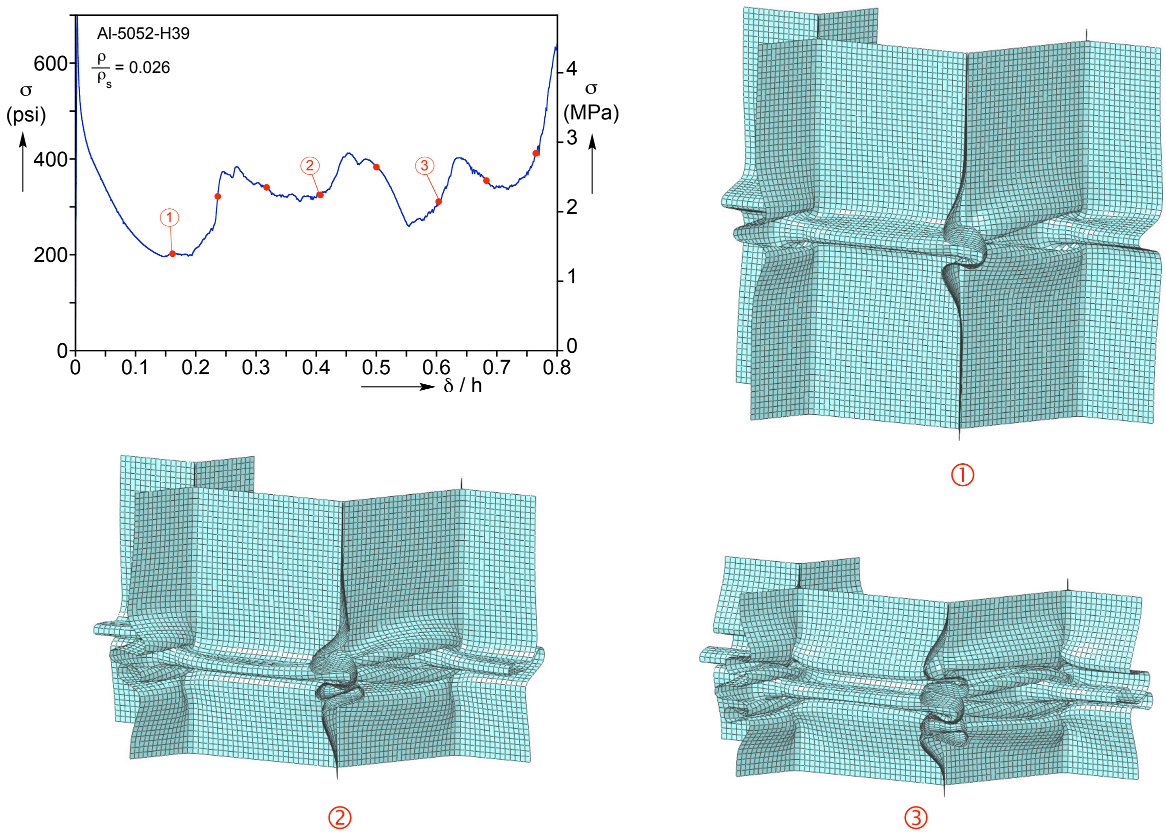

Fig. 3 Calculated stress-shortening response and corresponding crushing configurations.