A few issues in honeycomb mechanics

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Abstract

In engineering applications, honeycombs are made up of plates whose width dimension is in the order of 100 times the plate thickness or larger. Therefore, when a honeycomb is in-plane deformed, the plates in the honeycomb undergo *plane-strain bending* (some people refer to the deformation of the plates as *cylindrical bending*, which is actually the same as pure *plane-strain bending* because the stain or the effective force in the axial direction of the cylinder is zero for both *plane-strain bending* and *cylindrical bending*). Consequently, for honeycombs, the Young's modulus, the shear modulus and the elastic stress-strain relationship derived from beam elements (or the beam theory) have been under-estimated by a factor of $F_e = 1/(1-\nu^2)$, where ν is the Poisson's ratio of the solid material. For honeycombs made of a polymeric material, $\nu = 0.5$ and $F_e = 4/3$; for honeycombs made of a metallic material, $\nu = 1/3$ and $F_e = 9/8$.

For metallic honeycombs, the solid material is usually assumed to be an elastic and plastically power-law strain-hardening material. The strain-hardening component q is usually between 0 and 0.3 for a metallic material. If $q = 1$, the solid material is linearly elastic. Many people have used beam elements (or the beam theory) to analyse the plastic deformation, such as the yield strength or the yielding surface, of metallic honeycombs. Therefore, they have under-estimated the yield strength or the initial yielding surface by a factor of $F_p = 1/\sqrt{1-\nu+\nu^2} \approx 2/\sqrt{3}$, because the plates undergo plane-strain bending rather than plane-stress bending.

As to modelling the plastic energy absorption of a metallic honeycomb, it is more complicated to quantify the errors. It has been found that for a honeycomb made of a metallic material with $q = 0.1$ or smaller, if the honeycomb is in-plane crushed to an effective strain of about 60%, the maximum non-dimensional bending curvature in the plates can be larger than 1.5, the thickness of the plate can be significantly reduced (i.e. necking takes place) at the plastic hinge areas, and more than 90% of the external energy is absorbed by the plastic hinges. For an initially uniform metallic plate with a strain-hardening component q of 0 to 0.3, there is a peak point in the relationship between the non-dimensional bending moment and the non-dimensional bending curvature. Because the maximum bending moments in the plates always locate at the junctions of a honeycomb, necking or hinging will take place once the non-dimensional bending moment exceeds the peaking point. Therefore, the energy absorption ability of a metallic honeycomb depends largely upon the size of the plastic hinges (or the necking areas). Normally, the larger the solid material's strain hardening component q, the larger will be the plastic hinge, and hence, the larger the plastic energy absorption. Many people have used shell elements to model the crush of metallic honeycombs. However, the magnitude of maximum non-dimensional bending curvature and the size of the plastic hinges are very sensitive to the density of the mesh. Only when the relationship between the non-dimensional bending curvature and the size of the hinge is experimentally obtained for the solid material, can it be possible to exactly quantify errors in the crush simulations of metallic honeycombs using shell elements. Theoretical analysis can only give the range of the possible errors in the simulations.