INERTIA EFFECT IN THE IMPACT BEHAVIOUR OF CELLULAR MATERIALS

B. Hou*, H. Zhao**, S.Pattofatto** Y.L. Li*
**School of Aeronautics,Northwestern Polytechnical University,710072 Xi'an, China*
***Laboratoire de Mécanique et Technologie,ENS-Cachan/CNRS-UMR8535/Université Paris 6, 61 avenue du président Wilson, 94235 Cachan cedex, France*

Summary This paper studied experimentally the out-of-plane compressive behaviour for a series of aluminium honeycombs of different sizes and base materials (3003 and 5052) under impact loads. The testing results confirmed that there do exist a strength enhancement from 15% to 60% for different alloys (even the 3003 alloy and 5052 alloys have both rate sensitivities around 10%). In order to understand this impact enhancement difference, a comprehensive numerical investigation is performed to reproduce the experimental results for different cell size/wall thickness/base materials. Such simulated tests permit for an inside look of the detailed crushing process. Larger strain near intersectional edges of honeycombs is observed under impact loading. Different strain hardening behaviour between 3003 and 5052 alloys leads to different macroscopic enhancements. It shows that the lateral inertia is the main factor responsible for strength enhancement in impact crushing of aluminium honeycombs.

IMPACT STRENGTH ENHANCEMENT OF ALLUMINUM HONEYCOMB

This paper studied experimentally the out-of-plane compressive behaviour for a series of aluminium honeycombs of different sizes (relative densities varying from 1.78% to 4.72%) and base materials (3003 and 5052 alloys) under moderate impact velocities. The studied honeycombs are referenced by the single wall thickness *h*, and the minimum cell diameter *S* (Figure 1) and by their base materials.

The testing procedures[1] using large diameter Nylon Split Hopkinson bar were applied in a range of impact speed from 10m/s to 30m/s. The accuracy of such a Nylon SHPB system is proved to be enough to obtain reliable testing results for such soft materials. It is found that the impact enhancement for 5052 alloy honeycombs (<20%) is rather small, compared to that of the 3003 alloy honeycomb (>40%), noting that this is a general trend obtained from different wall thickness/cell size ratios in the same range of relative density (3 for 5052 and 4 for 3003) (see Figure 2).

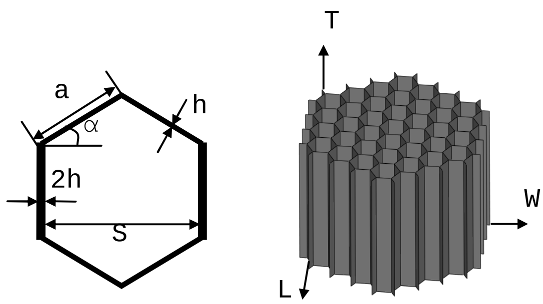


Figure 1 Geometry of the unit cell and hexagonal honeycomb specimens

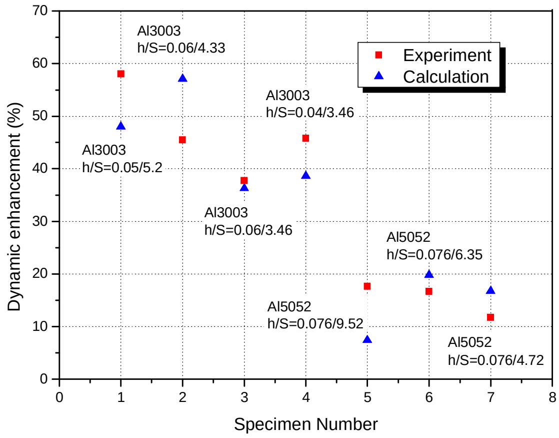


Figure 2 Summary of the calculating and experimental dynamic enhancement for both 3003 and 5052 alloys

The significant impact enhancement (>40% for 3003 honeycombs) cannot be directly derived from the rate sensitivity of the cell wall base materials which is rather weak. For a further investigation, honeycomb structures were modeled numerically (Figure 1) and the loading environment was modeled by two rigid planes moving at the prescribed velocities corresponding to those measured in the experiments. Commercial FEM code of ABAQUS/Explicit was employed for this simulated work. The numeric models follow well the experiments (Figure 2). Thus, this strength enhancement has its origin in the structural response and this structural response should be related to the constitutive relationship of two materials because the geometric and loading conditions are similar in numeric models for 3003 and 5052 honeycombs.

BUCKLING DELAY AND INERTIA EFFECT UNDER IMPACT LOADING

A possible structural effect is the buckling delay under impact loading[2]. In order to illustrate the main concept, a double-plate numerical model with dimensions comparable to honeycomb is built. The scheme of this model is shown in Figure 3a, which is composed of two plates connected with an angle (for the initial imperfection). The size of the model is in the same order with honeycomb cell walls with the plate thickness h=152μm, plate width b=1.833mm and height of one plate L=0.5mm, δ is the maximum deviation of plates from the vertical line, which represents the magnitude of initial imperfection of this model. A bilinear elasto-plastic material model till 20% strain and perfect plastic afterwards (as used in the simulation in the last section) was employed to describe the cell wall material of this aluminum honeycomb. For 5052 H38 honeycomb, a yield stress of 290 MPa and a small hardening is usually admitted in many previous works [3]. For 3003 honeycomb, parameters are identified initially with the tensile testing results of 1mm thick dog bone type 3003-O sheet specimen using universal testing machine and Split Hopkinson tensile bar test (figure 2b). One can see that its small rate sensitivity is confirmed. Figure 2C shows the calculated quasi-static and impact nominal stress-strain curves for both 3003 and 5052 alloys, compared with the prescribed constitutive relations. It can be found that the peak point (collapse point at which the curve begin to decrease rapidly) of the quasi-static curve coincides with the yield point of the material stress/strain curve. However, under impact loading, the collapse cannot take place at yield point because of lateral initial effect and the double plate model remains straight and compressed until the lateral speed is accelerated to a compatible level with the impact loading speed. Therefore, the collapse behavior of double-plate model under dynamic loading is characterized by a collapse delay effect. The model undergoes larger plastic strains in axial direction under impact loading before the collapse occurs. As the strain hardening curve is different, the stress increase due to this larger strain is different and especially the ratio of this stress increase over the yield stress is different. This is the believed reason for the strength enhancement difference between 5052 and 3003 honeycombs.

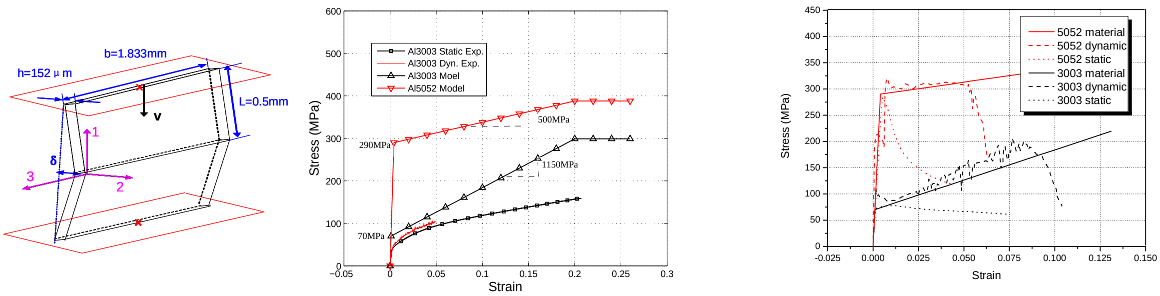
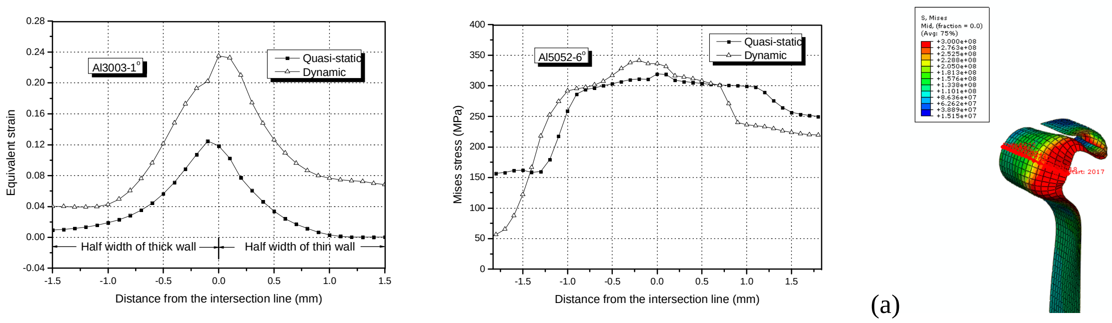


Figure 2 Double plate model (a, left), 3003 and 5052 alloys behaviour (b, middle), force enhancement (c, right)

INERTIA EFFECT IN THE SUCCESSIVE BUCKLING OF HONEYCOMBS

Such buckling delays exist also in the successive folding[4] of intersectional lines of Y-shape honeycomb cell model. Figure 3a depicts the stress profiles just before the buckling along the central line of one fold (see Fig. 3b) in both the double thickness wall and the simple thickness wall. On the one hand, there is a large difference of stress level between impact and quasi-static loadings for 3003 model which is due to the important hardening behavior of prescribed 3003 constitutive law, especially the ratio between the hardening and the yield stress. On the other hand, because of prescribed flat strain hardening for 5052 model, the stress level difference for 5052 is less significant even though a notable strain difference due to lateral inertia is observed.



(a) (b)

Figure 3: 3003 and 5052 stress profiles (a) deforming map (b)

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