12th International Conference on Sandwich Structures (ICSS-12) Lausanne - Switzerland, 19–22 August 2018
DOI: 10.5075/epfl-ICSS12-2018-236-238

QUANTIFICATION OF CORE CRUSH CHARACTERISTICS IN AIRCRAFT HONEYCOMB SANDWICH PANELS SUBJECT TO LOW-VELOCITY IMPACT

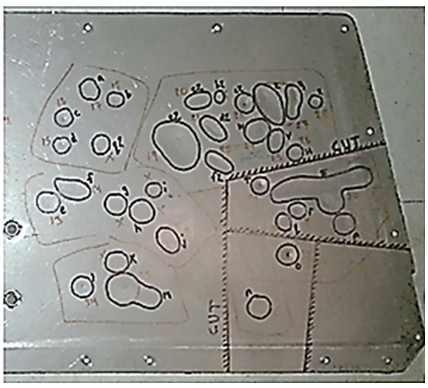
Diane Wowk[1], Tyler Reyno[2] and Catharine Marsden[3]
[1,2]Department of Mechanical and Aerospace Engineering, The Royal Military College of Canada, Canada.
[1]diane.wowk@rmc.ca, [2]tylerreyno@gmail.com
[3]Faculty of Engineering and Computer Science, Concordia University, Canada. c.marsden@concordia.ca

1. INTRODUCTION

Honeycomb sandwich structures are widely used for aircraft panels in such locations as the floors, exterior body and the wings due to their high stiffness to weight ratios. One drawback of these panels is that they are susceptible to damage from low-velocity impact events such as tool drops, runway debris or hail in the form of surface dents and plastic deformation in the core. The damage to the core is of particular interest because it is more difficult to detect and monitor than surface damage and it has been shown that core damage is a major contributor to the loss of residual strength of the panel [1]. Numerical simulations can be used to predict the reduction in residual strength, but only if the damage to the core is known. There is therefore a need to be able to anticipate the damage to the core based on the visible surface damage and panel configuration (skin thickness and core density). Finite element simulations performed by our research group indicated that for a given panel configuration, the depth of the core damage underneath dents of various sizes is constant and independent of the dent depth [2], but these predictions had not been validated experimentally. McQuigg *et al.* [1] also observed constant core damage depth in their experimental test results but the actual depth was not measured. In the study presented here, a retired aircraft sandwich panel with a dented aluminum face-sheet and an aluminum honeycomb core was sectioned to expose the core damage resulting from low-velocity impacts. The depth of the damage to the core was measured and it was confirmed that for the 20 dents in this particular panel it was constant and independent of the dent depth. Additional characteristics of the damaged core were also examined such as the number of lobes that developed in the cell walls and the interaction between the cell walls and the adhesive in order to better understand the relationship between the surface damage and the depth of core damage.

2. METHODOLOGY

The sandwich panel considered in this study was a 12.7mm (0.5”) thick, flat honeycomb aircraft panel as shown in Fig. 1(a). The panel had been dented during service and was retired when the allowable damage limits specified in the standard repair manual (SRM) were exceeded. A retired panel was used as opposed to experimental coupons so that a range of damage states resulting from natural variations of in-service impact events (oblique impact, impactors with different shapes, masses, and velocities) could be examined. The Al 7075-T6 top face sheet was 0.51mm (0.02”) thick and the Al 5052 core had a cell size of 3.2mm across the flats with a wall thickness of 0.025mm. The panel was sectioned across the largest diameter of 20 dents using a diamond blade saw at a cut rate of 1mm/s and a blade speed of 200rpm. Only dents with cutting planes that did not interfere with another dent were chosen. The dent depths ranged from 0.12 to 0.69mm with widths between 2.8 and 36mm measured using previously developed 3D laser scanning techniques [3]. The sectioned panel pieces were examined via optical microscope with 6.3-40 times zoom capability and photographed via a detachable digital camera for image processing in the open source software ImageJ. A 0.5 mm resolution ruler was aligned to the panel sections within the images to set the pixel/mm scale. The damaged cross section of the panel was identified by three regions as shown in Fig. 1(b); the surface damage region that includes the dent, the undeformed adhesive fillet region and the core crush region.



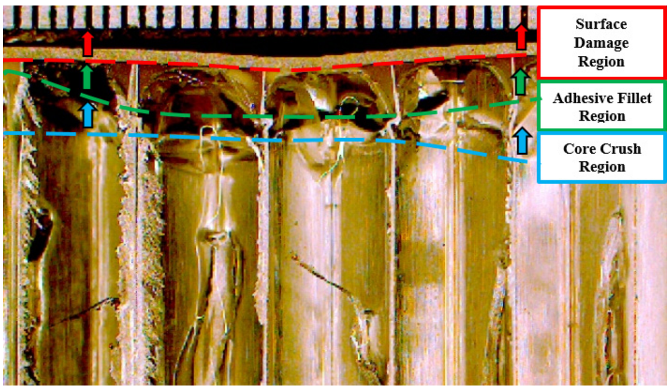
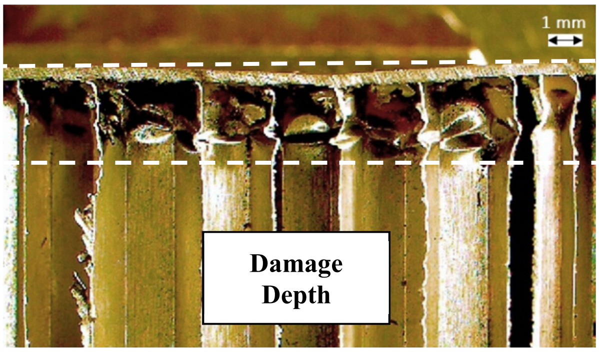


Fig. 1: (a) Retired aircraft panel with dented top face sheet. (b) Three distinct regions of the damaged panel.

3. RESULTS

Core Damage Depth

All of the damage to the core was concentrated within a region directly underneath the adhesive fillet as shown in Fig. 2(a). The concept of damage depth is introduced to describe the distance measured between the top of the undamaged face sheet and the maximum depth of the visibility identifiable core crush as illustrated in Fig. 2(a). For all 20 dents, the damage depth was observed to be constant and independent of the dent depth as shown in Fig. 2(b), with an average depth of 2.66 ± 0.85 mm (95%). The vertical axis in Fig. 2(b) is scaled to the thickness of the panel. This shows that for the 20 dents considered in this panel, different shapes or sizes of impact objects at different velocities or impact angles always produced the same damage depth.



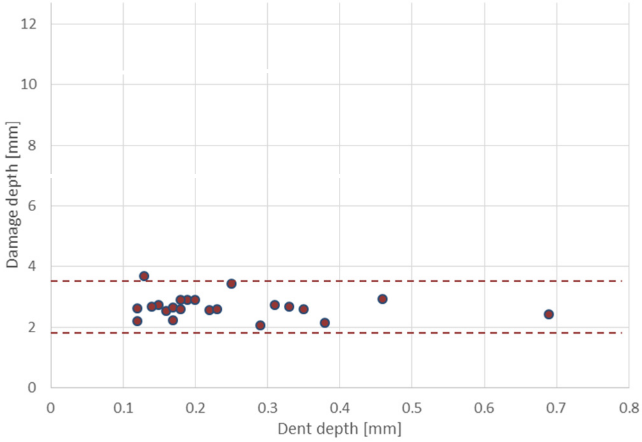
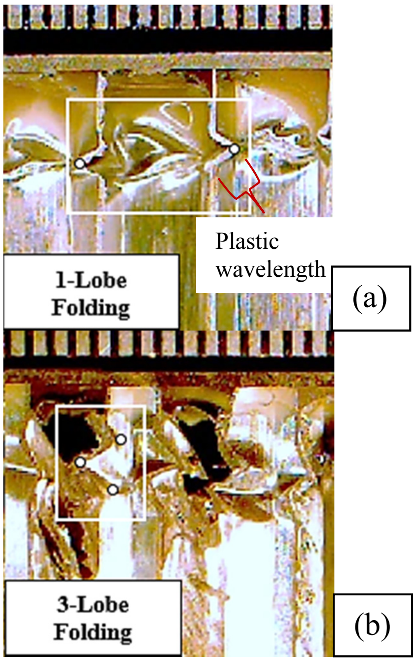


Fig. 2: (a) Damage depth dimension for damaged honeycomb sandwich panel with surface denting and core crushing. (b) Core damage depth plotted against dent depth; dashed lines represent a 95% confidence band.

Number of Lobes

Aminanda *et al.* [4] described the crushing process as the propagation of alternating cell wall folding from one side to the other, referred to as multi-lobe folding with the term "lobe" referring to the fold corner or plastic hinge of a buckled cell wall as shown in Figs. 3(a) and (b). Only 1-, 2- and 3-lobe folding was observed within the core of the panel. The number of lobes had no relation to the dent depth, and 1, 2 or 3 lobes could occur within the same dent. It was noted however, that 3-lobe folding typically occurred in cells with a smaller fillet radius and that 1-lobe folding occurred in cells with a larger fillet radius as shown by the graph in Fig 3(c).



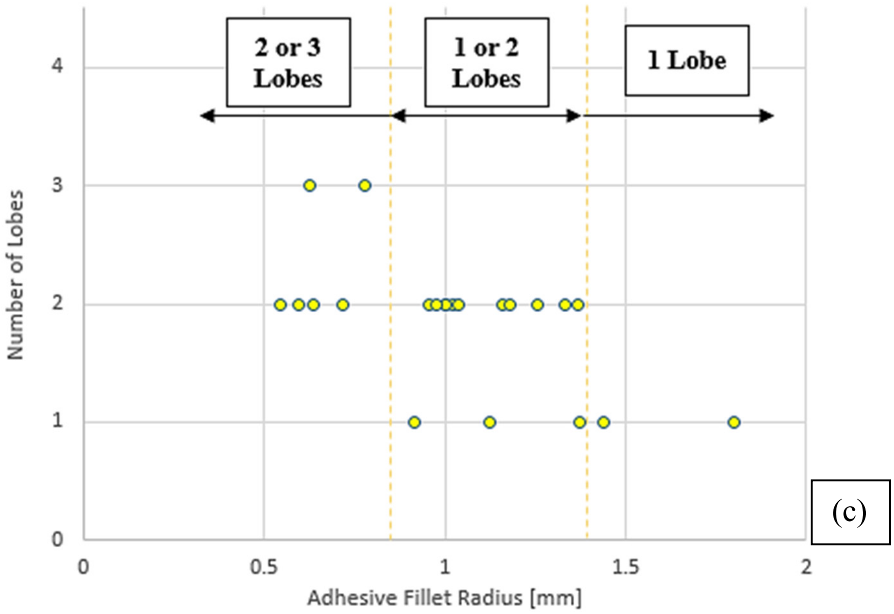


Fig. 3: (a) 1-lobe folding. (b) 3-lobe folding. (c) The number of lobes seen in a cell wall in relation to the fillet radius of the same cell.

4. DISCUSSION

Since the adhesive joining the facesheet to the core does not deform and the depth of the core damage is constant, each cell wall is only able to buckle or fold over the distance between the bottom of the adhesive fillet and the bottom of the damage depth. This means that the mechanisms of cell wall deformation must be able to accommodate the different lengths over which the cells have to deform, referred to here as the *effective length* and illustrated in Fig. 4(a). With the fillet radius being 1.07 ± 0.51 mm and the damage depth being 2.66 ± 0.85 mm, the effective length could theoretically vary between 0.23 and 2.95mm leading to many different modes of cell wall deformation. When a larger adhesive fillet radius is present, the effective length is smaller which resulted in cell walls with fewer folds as shown in Fig. 3(a). On the contrary, in Fig. 3(b), a smaller adhesive fillet radius resulted in a larger effective length and produced 3-lobe folding. Fig. 4(b) shows another deformation mode where the cell wall folded in a manner where the portion of the cell wall encased in the adhesive was not aligned with the undeformed cell wall below the damage region. The two lobes were positioned beside each other and exhibited a shear type of folding. Wu et al. [5] quantified core crushing based on the length of the folds in the cell walls, referred to as the plastic wavelength and labelled in Fig. 3(a). For the 96 folds present within the 20 dents, the average plastic wavelength was determined to be 0.56 ± 0.55 mm, but no clear trends could be identified with respect to the relationship with effective length. The angle of the folds was also measured, but again no trends could be identified.

While the core damage depth was consistent between dents and within dents, the number of lobes and the plastic wavelength revealed a high level of variability even within a single cell. Variability can be attributed to factors such differences in the adhesive fillet radius and the geometric irregularities observed within the honeycomb core. The adhesive fillet radius could be different on each side of a single cell wall, affecting the way the cell wall buckles. The cells in the honeycomb core were not perfectly hexagonal, and in some cases they appeared to be more of a diamond shape. In addition, the ribbon direction of the core has cell walls that are twice the thickness of those in the perpendicular direction leading to non-uniform buckling for the walls within a cell. The location of the cutting plane also added to the variation in the plastic wavelength and the fold angles as the cuts were not all positioned along the same cell orientation. It is important to keep in mind that in a numerical analysis the core is typically represented by an ideal geometry which buckles in a predictable and uniform manner, but physical aircraft panels show a high degree of variability in the deformation of the individual cell walls.

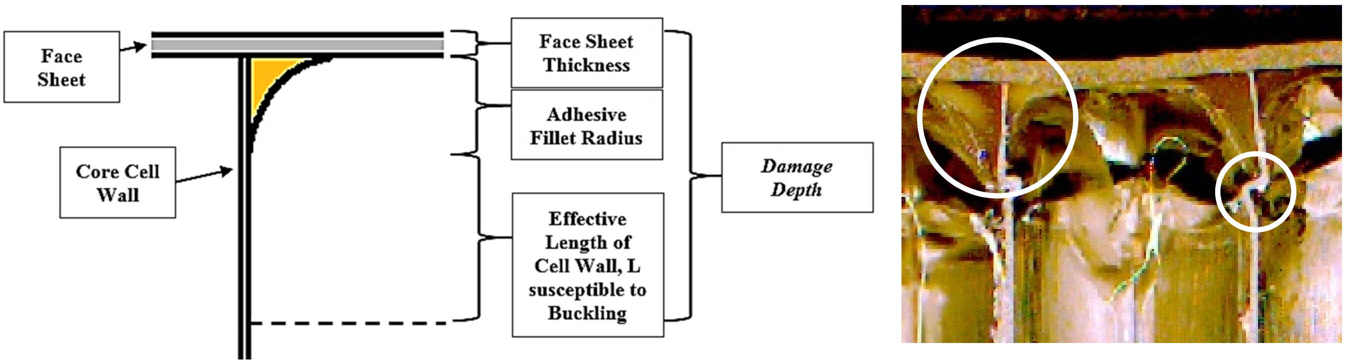


Fig. 4: (a) Definition of the effective length. (b) Cell walls deforming with a shear type of folding; uneven adhesive fillet radii on either side of a single cell wall.

5. CONCLUSION

Confirmation that the damage depth is constant for all dents within a panel is a key finding with regards to using numerical analysis to evaluate the effects of low-velocity impact damage on the residual strength of a honeycomb panel. It is expected that the size and shape of the damage to the core could be determined solely based on the core configuration and the thickness of the face sheet, facilitating the representation of core damage in a numerical model.

REFERENCES

[1] T. D. McQuigg, R. K. Kapania, S. J. Scotti and S. P. Walker "Compression After Impact Experiments on Thin Face Sheet Honeycomb Core Sandwich Panels", *J. Spacecr Rockets*, 2014; 51: 253-266.

[2] G. C. Clarke, "Characterization of Low Velocity Impact Damage in Metallic Honeycomb Sandwich Aircraft Panels Using Finite Element Analysis", Masters Thesis, The Royal Military College of Canada, 2017.

[3] T. Reyno, "Methods for Characterizing Surface and Core Damage in Aluminum Honeycomb Sandwich Aircraft Panels", Masters Thesis, The Royal Military College of Canada, 2017.

[4] Y. Aminanda, B. Castanie, J. Barrau, P. Thevenet "Experimental Analysis and Modeling of the Crushing of Honeycomb Cores", *Appl. Compos. Mater.*, 2005; 12: 213-227.

[5] E. Wu, W. Jiang, "Axial crush of metallic honeycombs". *Int J Impact Eng,* 1997, 19, 439-456.