CORRELATION OF DAMAGE CHARACTERISTICS IN DENTED ALUMINUM HONEYCOMB SANDWICH PANELS

Clarke, G[1*], Wowk, D[1], Marsden, C[2]
[1] Mechanical & Aerospace Engineering, Royal Military College of Canada, Kingston, Canada
[2] Centre for Engineering in Society, Concordia University, Montreal, Canada
* Corresponding author (Gregory.Clarke@rmc.ca)

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ABSTRACT

Sandwich panels consisting of an aluminum honeycomb core with aluminum face sheets are widely used in aerospace applications requiring a light weight yet relatively stiff structure. One downside of these panels is that they are easily damaged when subjected to impact events. The extent and severity of damage to the underlying core can be difficult to determine with NDT or visual inspection techniques.

In order to be able to determine the effect an impact will have upon the panel's residual stiffness and strength, the extent of the damage to the honeycomb core must be known. Existing literature is primarily focused upon panels with composite face sheets, and on damage more severe than Barely-Visible Impact Damage (BVID). In this paper, dynamic simulation using finite element analysis (FEA) was used to model BVID events, in order to predict the extent of the damage to the honeycomb core. Damage was quantified by the size and shape of both the resultant dent and the section of honeycomb core damaged. In order to obtain a wide range of damage profiles, simulations were conducted varying the properties of the impactor (radius, velocity, density) and the panel (core density, face sheet thickness).

In all cases studied, the core damage was confined to the area directly underneath the dent; for the baseline core density, the average depth of the damage remained within a range of 5.0 – 7.1 mm, and was independent of the dent depth. The average depth of the damage region was, however, affected by changes in the density of the core.

1 INTRODUCTION

When barely-visible impact damage (BVID) occurs, it can be difficult to determine the extent of the underlying damage using existing non-destructive testing methods. In particular, determination of the depth to which the damaged region extends typically requires cutting the panel in order to directly examine the core. The effect that an impact will have upon the residual strength and stiffness of a honeycomb sandwich panel will vary based upon the damage caused to both the face sheet and the honeycomb core. Horrigan and Staal [1] showed how the extent of the damage to the core can have significant impact upon the compressive strength of a composite honeycomb panel, with the reduced stiffness of the damaged core region leading to localized face sheet wrinkling and subsequent buckling of the entire panel.

Analytical approaches in the literature to calculating the residual strength of a sandwich have focused upon the effect of the damage to the core, and neglect the effect that the surface dent itself has on the face sheet's contribution to the buckling resistance. FEA techniques can incorporate both the effect of the dent shape and the underlying damage, allowing for a simulation of a panel with a realistic damage representation under its actual loading conditions to be conducted. Modelling dents with realistic damage will allow for a more accurate determination of whether or not a honeycomb sandwich panel remains serviceable than the currently used criteria, which are based strictly upon dent area and depth.

Such modelling of the dented configuration of a panel requires knowledge of the correlation between the characteristics of the dent profile and the extent of the damage to the underlying core. Existing literature on the topic, such as Wadsworth et al [2], focused upon sandwich panels involving composite materials. The focus of the current study is to investigate the relationships between the measurable parameters of a dent in the face sheet of an aluminum-aluminum honeycomb sandwich panel, and the extent of the damage to the underlying honeycomb core.

This study utilized FEA in order to simulate BVID events under a wide range of conditions. The results were used to determine correlations between damage to the honeycomb core and the size and shape of the residual dent in the face sheet.

2 METHODOLOGY

2.1 Baseline model

The analysis was conducted using the AUTODYN explicit dynamics solver in the ANSYS FEA software program. It incorporated inertia, contact between an impactor and the top face sheet, plasticity in both the face sheets and the honeycomb core, and a strain based material failure criteria. A baseline model for a 50.8 mm x 50.8 mm (2" x 2") aluminum – aluminum honeycomb sandwich panel was made, with face sheets for the panel consisting of 7075-T6 aluminum, 0.3048 mm thick (0.012"). They are separated by a honeycomb core made of 5056 H39 aluminum, 12.7 mm (0.5") thick, with cell walls 0.0254 (0.001") thick in the off-ribbon direction, and 0.0508 mm (0.002") in the ribbon direction, with a cell size of 3.175 mm (1/8") across the flats. Table 1 outlines the material properties for the study, with both materials using bilinear isotropic hardening, and a maximum equivalent plastic strain as the failure criteria.

	7075-T6 (Face Sheet) [3]	5056 H38 (Core) [4]	Structural Steel (Impactor) [5]
Density	2804 kg/m^3	2640 kg/m^3	7850 kg/m^3
Young's Modulus	71.7 GPa	71 GPa	200 GPa
Poisson's Ratio	0.33	0.33	0.30
Yield Strength	503 MPa	345 MPa	N/A
Tangent Modulus	500 MPa	500 MPa	N/A
Max. Equivalent Plastic Strain	0.11	0.15	N/A

Table 1. Material properties used for honeycomb sandwich panel simulation

The impactor is modelled as a structural steel sphere with a radius of 25.4 mm (1"). For the baseline case, the impactor is given an initial velocity of 2.0 m/s, resulting in a kinetic energy level of 1.07 J, a level chosen because it results in BVID.

The mesh has a finer sizing in the area near the impact. Sections of the core, face sheet, and impactor outside this region are given a coarser mesh sizing. This helps minimize simulation run-time while still allowing for the model to accurately capture the more extreme deformation and stresses occurring nearest to the impact. Figure 1 shows a cross-sectional view of the baseline model and its mesh. The simulation was run until the impactor had rebounded and the dent in the face sheet had elastically relaxed.

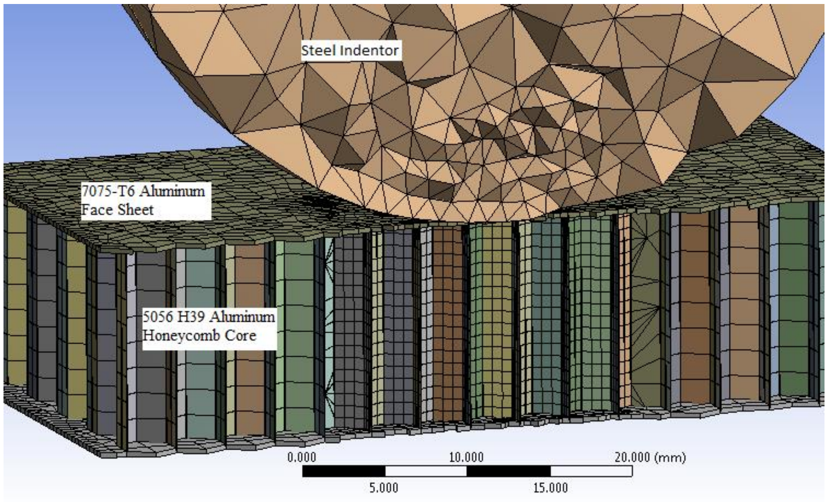

Figure 1: Cross section view of baseline model

2.2 Variations to baseline conducted.

In order to obtain a wide range of damage results, multiple series of simulations were conducted. In each series, one parameter was changed from the baseline model, as outlined in Table 2. Studies were conducted varying the impactor velocity, the impactor density (adjusting it such that the kinetic energy levels matched those in the velocity study), the face sheet thickness, the honeycomb core density (by adjusting both the cell wall thickness and the cell size), and the impactor size (adjusting the density as required to maintain a constant mass, and thus constant kinetic energy level).

	Impactor velocity (m/s)	Impactor Mass (kg)	Impactor Kinetic Energy	Impactor Radius (mm)	Face Sheet Thickness (mm)	Core wall thickness (mm)	Core cell size (mm)
Impactor velocity study	1.5, 2.0, 2.5, 3.0, 3.5, 4.0	0.54	0.6, 1.1, 1.7, 2.4, 3.3, 4.3	25.4	0.30	0.025	3.2
Impactor Density study	2.0	0.30, 0.54, 0.84, 1.21, 1.64, 2.15	0.6, 1.1, 1.7, 2.4, 3.3, 4.3	25.4	0.30	0.025	3.2
Face sheet thickness Study	2.0	0.54	1.1	25.4	0.10, 0.15, 0.30, 0.46, 0.61, 0.91, 1.22	0.025	3.2
Core density study	2.0	0.54	1.1	25.4	0.30	0.018, 0.025, 0.051	3.2, 4.8, 6.4, 9.5
Impactor size study	2.0	0.54	1.1	6.4, 12.7, 19.1, 25.4, 31.8, 38.1, 50.1	0.30	0.025	3.2

Table 2: Parameters varied for each series of simulations

2.3 Damage criteria

The face sheet dent is identified as any deformation greater than 0.01 mm, a threshold chosen as a value at which all simulations saw the most pronounced transition between a relatively flat profile and a distinct dent shape. The dent depth was taken as the point of maximum deflection in the face sheet, and the dent width was determined by the distance between points on either side of the dent where the 0.01 mm threshold is exceeded.

The honeycomb core damage criteria was determined by examining a cross section view of the core, and determining which areas experienced plastic strain above the typical 0.2% threshold commonly used to determine the onset of yielding. The maximum depth to which this yielding extended was measured, as well as the average of the maximum depth for each cell, across the damage region. The width of the damage region was measured between the two outer cell walls of the region experiencing yielding. Figure 2 shows an example of such a measurement.

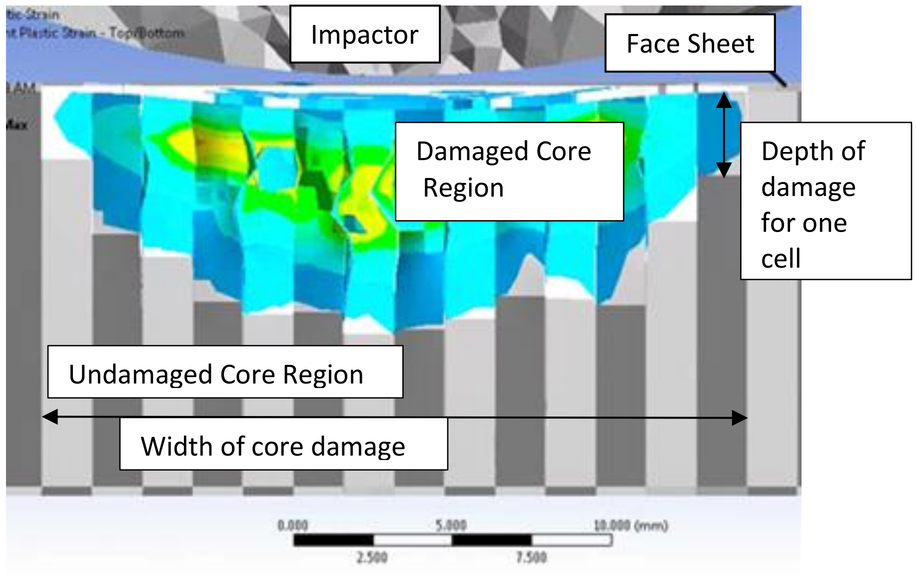

Figure 2: Core damage measurement, with coloured region indicating yielding.

3 RESULTS

3.1 Dent profile

The dent depth and width develop independently from each other and the relationship depends upon which parameter was varied. The velocity and density studies both showed an increase in the dent width and the dent depth as the kinetic energy increased, with both parameters increasing proportionally as shown in Figure 3. The core density study also showed a similar trend with dent depth and width decreasing as core density increased. Varying the size of the impactor saw the opposite trend, with deeper dents caused by smaller impactors being less wide than the shallower dents caused by larger impactors, as seen in Figure 4. Increasing the skin thickness saw little change in the width of the resultant dents, but resulted in a reduction of the dent depth, as shown in Figure 5.

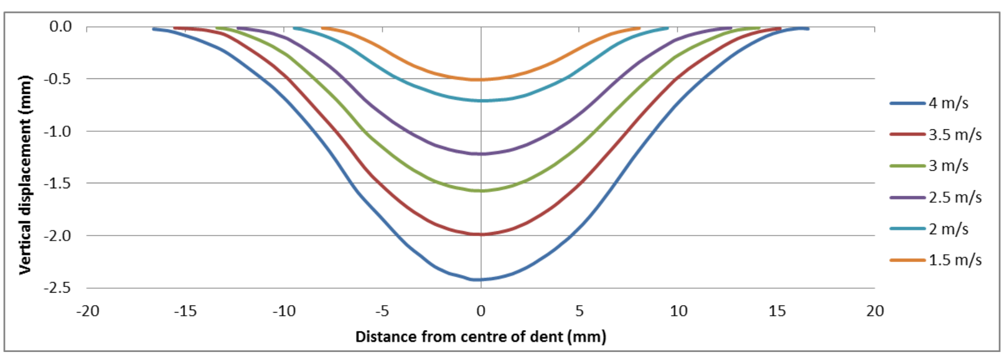

Figure 3: Dent profiles for different impactor velocities

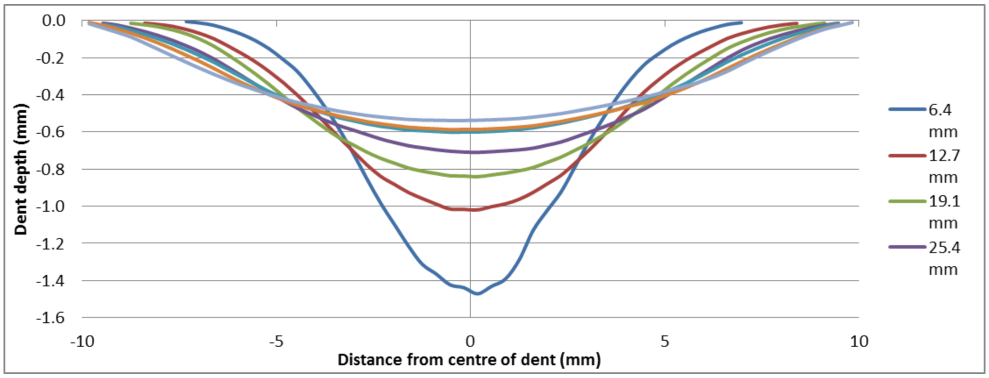

Figure 4: Dent profiles for different impactor radiuses, at constant energy levels

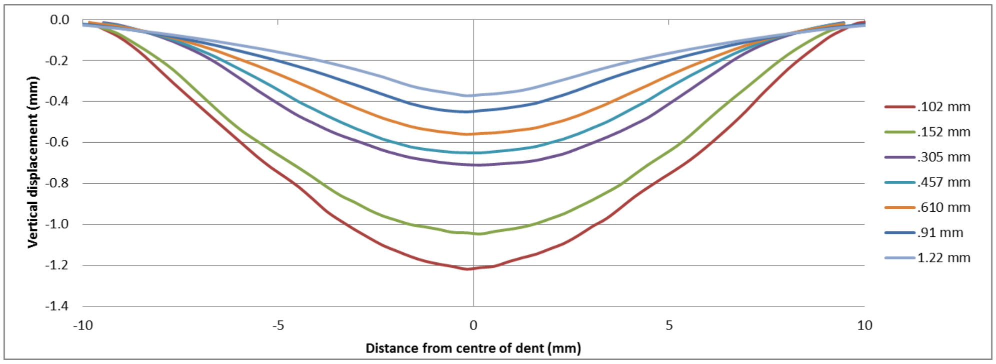

Figure 5: Dent profiles for different face sheet thicknesses, at constant energy levels

3.2 Core damage

The shape of the damaged area changed with the kinetic energy of the impact, with the cross section of the damage region for lower energy impacts being more triangular, and higher energy impacts being more rectangular in shape, as seen in figure 6.

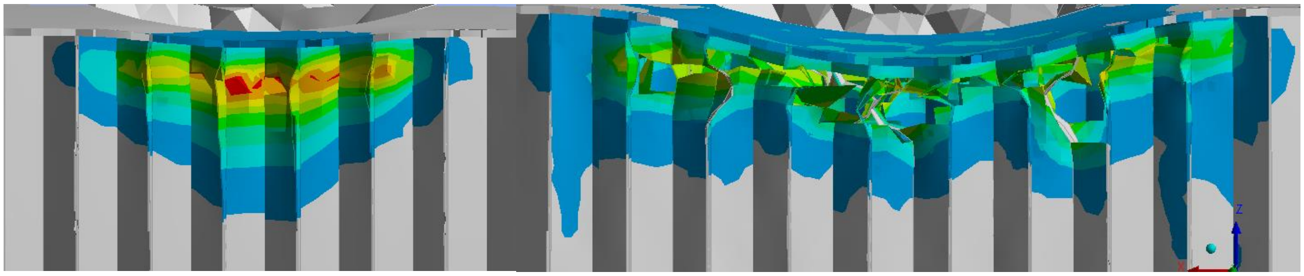

Figure 6: Side by side comparison of shape of damage region for low energy (0.6 J; left) and high energy (4.3 J; right) impact from the velocity study, coloured region indicating yielding.

The most evident overall trend discovered is that the width of the core damage area has a direct relationship with the width of the residual dent. When the face sheet is dented downwards, yielding occurs in the cell walls directly below it, and this damage did not extend past the region immediately underneath the dent. Figure 7 shows this relationship for all series of simulations examined. The slope of 1 indicates that the face sheet dent and the region of core damage have the same width.

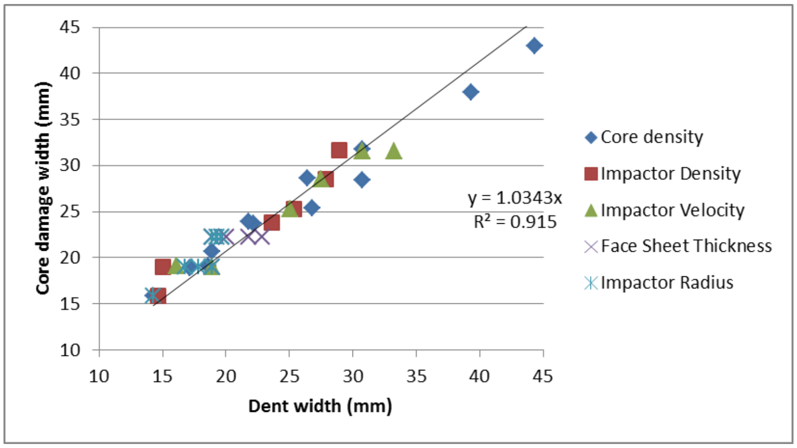

Figure 7: Core damage width versus dent width for all studies

When varying the impactor parameters and the face sheet thickness, the average depth of the core damage was found to lie within a range of 5.0 – 7.1 mm, and was independent of dent depth. Figures 8 and 9 show the relationship between the average core damage depth and the dent width and depth respectively.

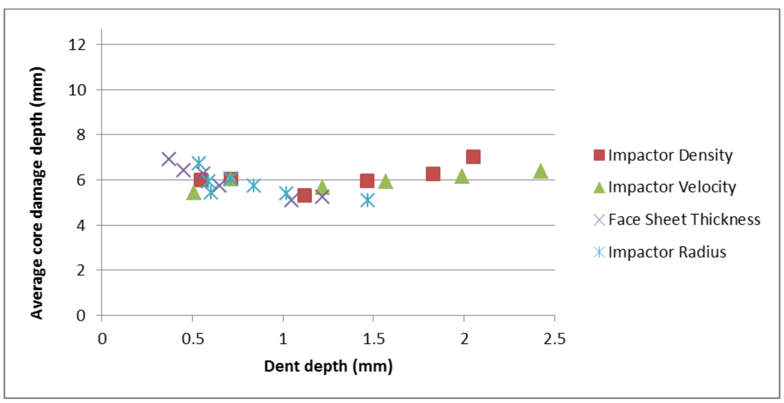

Figure 8: Average core damage depth versus dent depth, for the studies varying the impactor and the skin thickness.

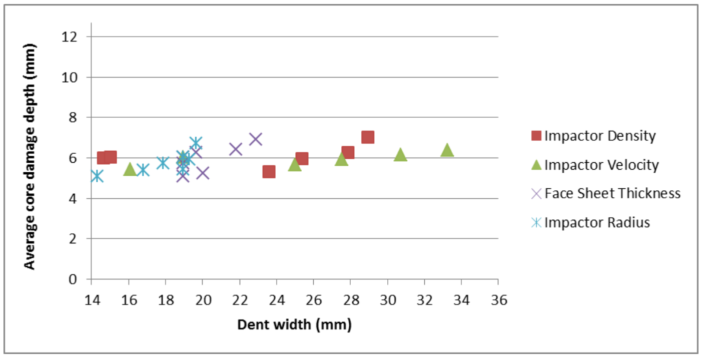

Figure 9: Average core damage depth versus dent width, for the studies varying the impactor and the skin thickness.

The only parameter that affected the depth of the core damage region was core density, where less dense cores resulted in a deeper yield region as seen in Figure 10. Less dense cores also resulted in larger dent widths, and a linearly increasing trend was seen between the depth of the core damage and the dent width as illustrated in Figure 11.

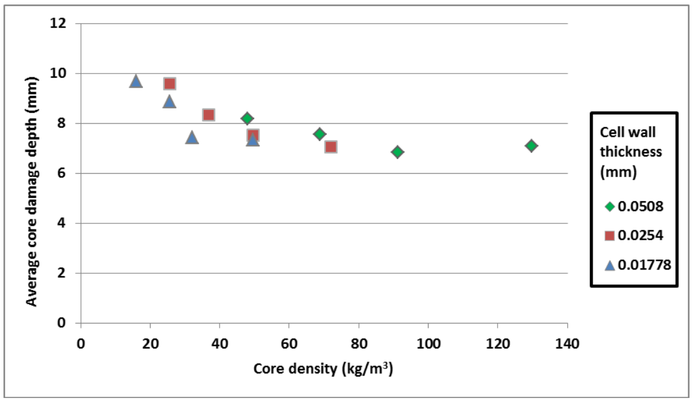

Figure 10: Average core damage depth versus core density, for core density study

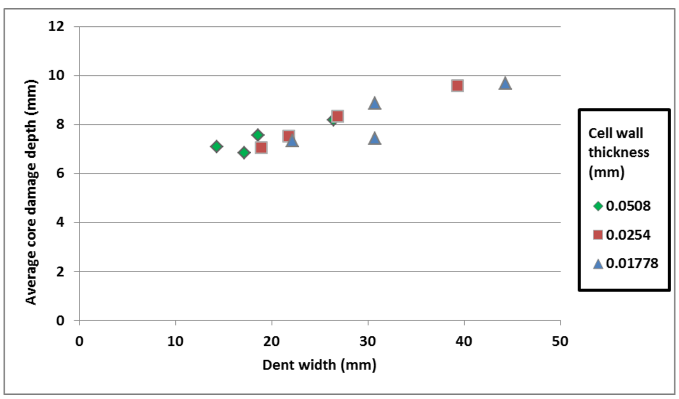

Figure 6: Average core damage depth versus dent width, for core density study

4 DISCUSSION

Section 3.2 showed that there was no significant change in the average core damage depth, when the properties of the honeycomb core remain constant. Honeycomb core is designed to readily absorb impact energy, by plastic deformation through crushing. When impact occurs, the cell walls are loaded in axial compression up until they reach their peak load, after which buckling occurs and crushing of the structure initiates. Figure 12 shows a typical load / displacement curve for the loading to failure of a crumpling honeycomb core. Once crushing has been initiated, the load resisted by the honeycomb core drops dramatically, and the effective stiffness becomes negligible as further crushing continues without any increase in load.

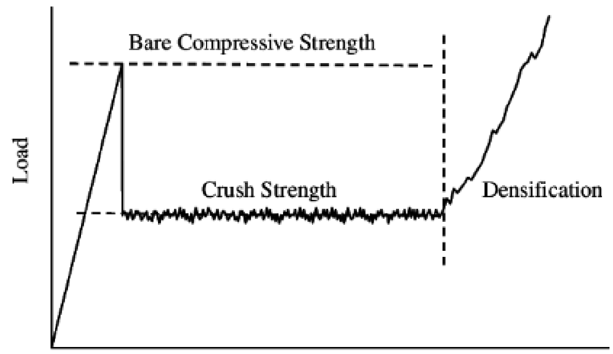

Figure 7: Typical Honeycomb Core Crush Curve [6]

The effect that this has upon the crush depth is that once a section of honeycomb core buckles and begins to crush, the damaged region will not extend deeper until the initially crushed cells have completely collapsed as indicated by the densification region in Figure 12. This is because the load that the damaged section of the core is able to transfer to the undamaged section of the core will be less than the peak load required to initiate the onset of further buckling and subsequent crushing of previously undamaged areas. This is illustrated in Figure 13, which shows a side-by-side comparison of a damage region immediately after impact, and at the point where the impactor displacement is at its maximum, before rebounding. The section of the core which is directly below the impact starts crushing initially, and once it has started crushing, the damage does not spread any deeper because the crushed section of the core cannot transfer any load. As the impact progresses, a larger area of the face sheet is pushed downwards, causing the crushing to spread outwards from the centre, however the increased displacement of the section of the face sheet at the point of the impact results in more extensive crushing of the already crushed region underneath it, rather than deeper crushing.

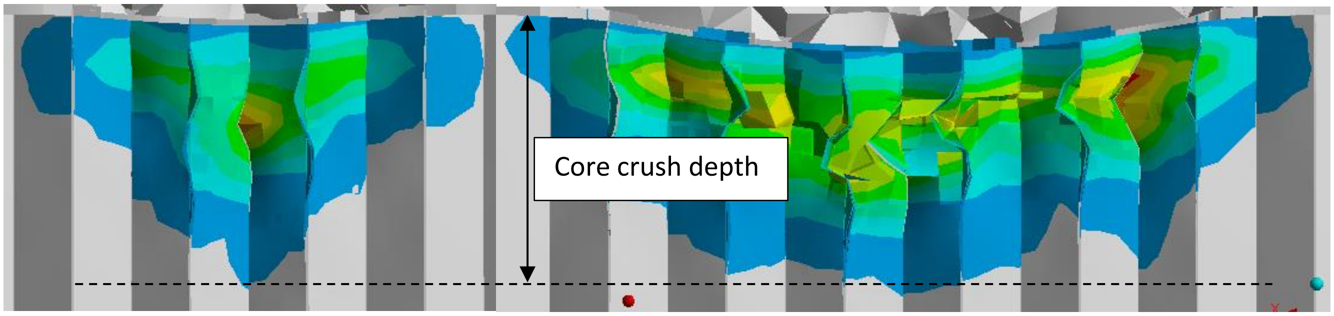

Figure 8: Depth of core damage region, immediately after impact (left) and at point of maximum displacement of impactor (right)

This explains why the dent depth and the depth of the crushed region of the core are independent of each other. Any type of impact which drives the face sheet further into the core will not necessarily cause deeper core damage, because the additional energy of the impact is absorbed by more extensive crushing rather than a deeper crush region. Impacts severe enough to cause complete crushing of the core would be too severe to be considered BVID. The depth over which this crushing occurs is therefore a function of the properties of the honeycomb itself, rather than the face sheet or the impactor.

5 CONCLUSION

It has been shown that the width of the core damage region, based upon cell wall yielding, can be assumed to be the same as the dent width. For simulations using the baseline core density, the average depth of the damaged core is independent of the dent depth and the dent width, and was within a relatively narrow range of 5.0 – 7.1 mm. The depth of the damaged core was only dependent on the core density. These results show that the size of the core crush region can be estimated, in order to construct simulations of panels with pre-existing damage. This will simplify the process of evaluating residual strength and stiffness for various dent configurations.

6 REFERENCES

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