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Compressive failure of quasi-static indented CFRP/aluminium honeycomb sandwich panels

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Abstract. The present study examines sandwich panels, which are made of carbon fiber facesheets with aluminium honeycomb core and focuses on how varying factors (skin thickness, layup, core density and diameter of hemispherical indenter) are affecting collapse of artificially damaged panels in edgewise compression. Damage in the middle of sandwich specimens was introduced using quasi-static indentation. Hemispherical indenters of two diameters, namely, 20 mm and 150 mm, were applied. The residual strength was estimated through the edgewise compression test of damaged specimens. The study demonstrated that increase of the honeycomb density led to decrease in the safety margin in structure. Thicker skins may also lead to a catastrophic propagation of indent.

1. Introduction

Ultra lightweight sandwich construction materials are increasingly used in the aerospace structures due to their high specific stiffness and strength, corrosion resistance, and fatigue performance. Nevertheless, the major drawback of this structure is its susceptibility to localized impact damage caused by accidental out-of-plane load (tool dropping, hail stones, or runway debris) during the manufacturing process and/or service life [1-4]. This may lead to skin delamination and fracture, skin-core debonding, core crushing and shear failure [4]. Damage tolerance is affected by a multitude of factors, from panel construction to boundary conditions [3]. Current research focuses on failure characterization of in-plane loaded sandwich panels. The experimental set-up and testing were performed according to the ASTM standards. Artificial damage introduction in sandwich panels was carried out using quasi-static indentation. Although impact test is closer to real accidental dropping of an object on panel, quasi-static indentation is also a popular approach because it can be easier simulated with a numerical model.

2. Materials and Methods

2.1. Manufacturing of specimens

Composite skins were manufactured by laid up unidirectional pre-preg (Unipreg® 100) with a ply thickness of 0.1 mm and thermal consolidation in mechanical press under pressure of 0.3 MPa and temperature of 120 °C. Three different lay-ups (90/0), (-60/+60/0) and (0/-60/+60/0) were used. Also, three different 5052 aluminium honeycomb cores of 20 mm in thickness were selected for the study. More detailed information about density and cell size is shown in table 1. For interfacial bonding an epoxy-based paste adhesive Permabond E538 was used. To improve adhesion, the skins were



processed with P120 sandpaper and degreased before bonding. 0° direction of the carbon fibres was aligned with the ribbon direction of the honeycomb core. Complete panel of 210×460 mm was machined into 6 specimens of 100×150 mm with the longer side aligned with the direction of edgewise compressive loading. After artificial damage introduction, specimens were dipped into an epoxy/sand mixture 20 mm from the ends. Cured resin forms an end-potting that prevent undesirable and premature failure of specimen ends. A complete specimen is shown in figure 1.

Table 1. Density and cell size of honeycombs used in the study.

Cell size (mm)	Density (kg/m ³)	Aluminium foil thickness (mm)
6.4	23.63	0.0178
3.2	49.66	0.0178
3.2	97.71	0.0381

2.2. Artificial damage introduction

Panels were damaged with quasi-static (QS) indentation by evenly pushing HS indenter into specimen skin with constant, 1 mm/min speed until predetermined displacement threshold from 0.5 mm to 2.5 mm was reached. Tests were performed in line with basic principles of ASTM D6264 and carried out on INSTRON E3000 universal testing machine. Each specimen was fixed with 4 rubber pads on steel frame with inner dimensions of 125×75 mm (figure 2). To compare the effect of indenter's diameter on damage propagation during in-plane compressive load, two different diameter (20 mm and 150 mm) hemispherical (HS) indenters were applied.

2.3. Edgewise compression test

After artificial damage is introduced in specimen, an appropriate and robust method for residual strength estimation must be applied. Edgewise compression test (popularly known as compression-after-impact (CAI) test [4]) was carried out by placing specimens between two steel plates in universal testing machine ZWICK Z100 and statically loaded with 0.5 mm/min rate. Lower compression plate was equipped with hemisphere to provide uniform distribution of the load. CAI test setup is shown in figure 3.

3. Results and Discussion

A summary of all tests is depicted in 3D graphs where simultaneous effect of three variables: honeycomb density, number of plies in facesheet (layup) and indent depth can be seen. Figure 4 shows the distribution of failure types for panels indented with 20 mm punch and figure 5 - with 150 mm punch respectively. Round markers represent panels with appropriate/satisfactory failure type, which means that these panels failed because of damage made by the indenter, while triangle markers show cases of inappropriate/unsatisfactory failures where damage was not affecting the panel enough to provoke failure. There is also a third group of cross shaped markers which are undamaged panels for a common reference. Data from 3D graphs is also shown in tables. Table 2 for intact panels, table 3 contains results of panels indented with 20 mm indenter and table 3 represents results of panels damaged with 150 mm indenter, plus and minus signs points to satisfactory or unsatisfactory failure of the panels. Schematic pictures of major failure types are shown in Figure 6. The very first attempts in practical testing showed, that there are several combinations of sandwich panel constructions where even visible damage under edgewise compression load does not cause premature failure. It can clearly be seen in 3D graphs (Figures 4 & 5) that many specimens did not fail appropriately. To be exact only 37% of panels damaged with 20 mm indenter had satisfactory failure type and the same index for 150 mm indenter was 42%. Not that much damage size, but panel construction is affecting the final failure

of the panel. For intact panels under edgewise compression load the most commonly observed failure type was skin crack and skin buckling simultaneously, about 38 % of the cases. Also, skin crack itself and skin buckling inside the panel with no cracks was observed. In case of indent provoked failures also most common was simultaneous skin crack and skin buckling. Under in-plane compressive load the indent was progressing from middle to panel sides making skin to buckle and when certain deformation is reached, in one moment skin cracks all way through the panel's width.



Figure 1. Complete sandwich panel specimen with reinforced ends for edgewise compression.

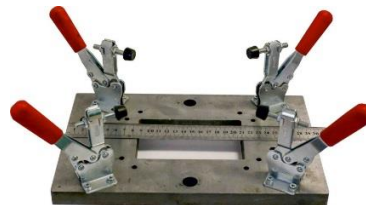


Figure 2. Steel frame for specimen fixation during quasi-static indentation test.



Figure 3. Edgewise compression test setup.

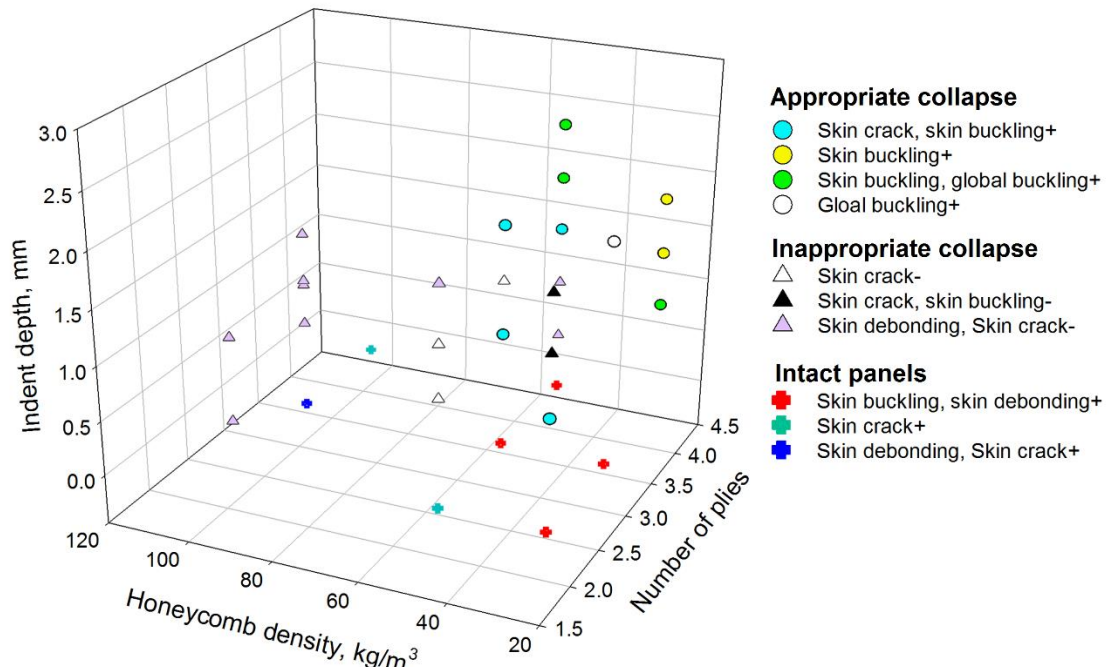


Figure 4. Distribution of failure types in edgewise compression test after out-of-plane quasi-static indentation with 20 mm indenter. Failure types distributed depending on honeycomb density, number of plies in facesheet and indent depth. All circle shaped markers show failures caused by artificial damage, triangles – inappropriate failures and crosses represents intact specimens.

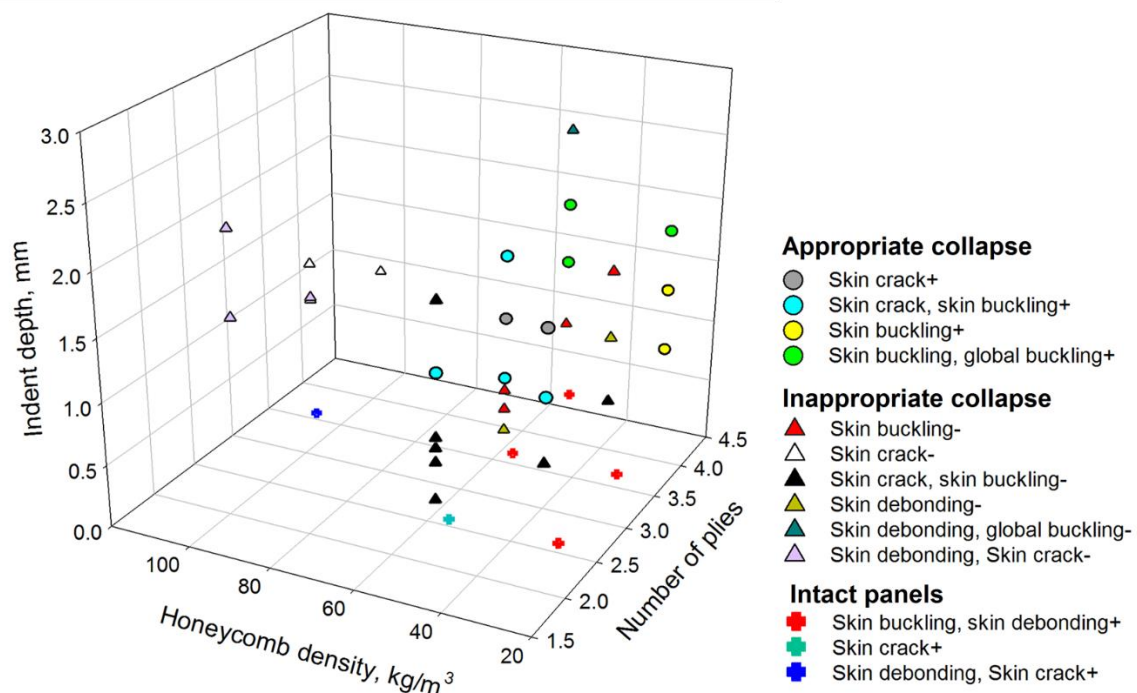


Figure 5. Distribution of failure types in edgewise compression test after out-of-plane quasi-static indentation with 150 mm indenter. Failure types distributed depending on honeycomb density, number of plies in facesheet and indent depth. All circle shaped markers show failures caused by artificial damage, triangles – inappropriate failures and crosses represents intact specimens.

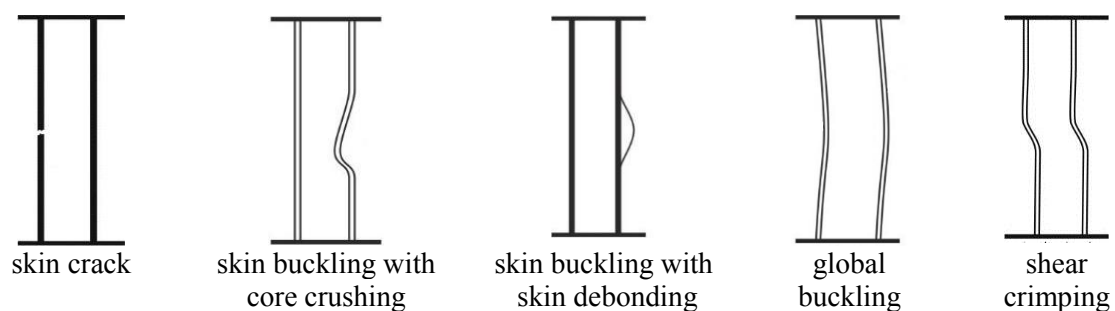


Figure 6. Major groups of sandwich panel failure types in edgewise compression test [3].

Table 2. Summary of failure types of undamaged specimens in edgewise compression.

No.	Facesheet lay-up	Honeycomb density (kg/m ³)	Failure
1	[90/0]	25.63	Skin crack, skin buckling
2	2 plies	49.66	Skin crack
3		25.63	Skin buckling, skin debonding
4	[-60/+60/0]	49.66	Skin crack, skin buckling
5	3 plies	97.71	Skin debonding, skin crack
6			Skin debonding, skin crack
7	[0/-60/+60/0]	49.66	Skin crack, skin buckling
8	4 plies	97.71	Skin crack

Table 3. Failure types in edgewise compression tests of panels damaged with 20 mm punch.

No.	Facesheet lay-up	Honeycomb density (kg/m ³)	Indentation depth (mm)	Failure
1	[90/0] 2 plies	25.63	1.0	Skin buckling, skin crack-
2			1.5	Skin crack, skin buckling+
3			2.0	Skin crack+
4		49.66	0.5	Skin buckling, skin crack-
5			0.8	Skin buckling, skin crack-
6			0.9	Skin buckling, skin crack-
7			1.0	Skin buckling, skin crack-
8			1.5	Skin crack, skin buckling+
9			2.0	Skin buckling, skin crack-
10		97.71	1.6	Skin debonding, skin crack-
11			2.3	Skin debonding, skin crack-
12	[-60/+60/0] 3 plies	25.63	1.0	Skin buckling, skin crack-
13			1.5	Skin debonding-
14			2.0	Skin buckling-
15		49.66	0.6	Skin debonding-
16			0.8	Skin buckling-
17			0.9	Skin buckling-
18			1.0	Skin crack, skin buckling+
19			1.5	Skin crack+
20			2.0	Skin crack, skin buckling+
21		97.71	1.3	Skin debonding, skin crack-
22			1.5	Skin crack-
23			1.5	Skin crack-
24	[0/-60/+60/0] 4 plies	25.63	1.0	Skin buckling+
25			1.5	Skin buckling+
26			2.0	Skin buckling, global buckling+
27		49.66	1.0	Skin buckling-
28			1.5	Skin buckling, global buckling+
29			2.0	Skin buckling, global buckling+
30		97.71	1.0	Skin crack-

Skin thickness also had significant influence on dent propagation during edgewise compression. Only 21% of all 2 ply facesheet panels failed due to damage, for 3 ply facesheets this index is quite higher – 30%, while panels with 4 ply skins in 73% of all tests failed due to propagation of indent. By decrease of density, the probability that damage will provoke collapse increases. 63% of panels with 25.63 kg/m³ core had satisfactory failure types, in case with 49.66 kg/m³ core only 42% of collapsed specimens belongs to the same group, but none of specimens with honeycomb density of 97.71 kg/m³, made of thicker (0.0381 mm) foil, had satisfactory failure. This leads to a conclusion, that denser honeycomb has higher capacity to stabilize the facesheets even when its slightly crushed. Finally, it is obvious that larger dent depth increases the possibility of affecting specimen's fail in edgewise compression. Similarly, 29% of panels with 1 mm indent failed due to dent propagation, 47% with 1.5 mm indent and 62% with 2 mm indent.

Table 4. Failure types in edgewise compression tests of panels damaged with 150 mm punch.

No.	Facesheet lay-up	Honeycomb density (kg/m ³)	Indentation depth (mm)	Failure
1	[90/0] 2 plies	25.63	1.0	Skin crack, skin buckling+
2			1.5	Skin crack, skin buckling-
3			2.0	Skin crack, skin buckling-
4		49.66	1.0	Skin crack-
5			1.5	Skin crack-
6			2.0	Skin debonding, skin crack-
7	[-60/+60/0] 3 plies	97.71	0.5	Skin debonding, skin crack-
8			1.0	Skin debonding, skin crack-
9			2.0	Global buckling+
10		49.66	1.0	Skin crack, skin buckling+
11			1.5	Skin crack-
12			2.0	Skin crack, skin buckling+
13	[0/-60/+60/0] 4 plies	97.71	0.8	Skin debonding, skin crack-
14			1.0	Skin debonding, skin crack-
15			1.0	Skin debonding, skin crack-
16		25.63	1.5	Skin debonding, skin crack-
17			1.0	Skin buckling, global buckling+
18			1.5	Skin buckling+
19	[0/-60/+60/0] 4 plies	49.66	2.0	Skin buckling+
20			0.5	Skin debonding, Skin crack-
21			1.0	Skin debonding, Skin crack-
22			1.5	Skin crack, skin buckling+
23		25.63	2.0	Skin buckling, global buckling+
24			2.5	Skin buckling, global buckling+

4. Conclusions

Aluminium honeycomb sandwich panels with 2 to 4 ply skins and core density between 25.63 and 97.71 kg/m³ were manufactured, damaged with out-of-plane quasi-static indentation from 0.5 to 2.5 mm into panel's surface. The edgewise compression test showed that dominant failure types were skin cracking and skin buckling. Collapse of more than a half of panels was not provoked by artificial damage. Most likely this was due to excessive honeycomb density and insufficient penetration depth, as well as too thin facesheets. The sandwich panels with low core density and thick facesheets are more susceptible to barely-visible impact damage.

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References

- [1] Wei T, Falzon B G, Chiu L N S and Price M 2015 Predicting low velocity impact damage and Compression-After-Impact (CAI) behavior of composite laminates *Compos. Part A-Appl. S.* **71** 234
- [2] Petit S, Bouvet C, Bergerot A and Barrau J J 2007 Impact and compression after impact experimental study of a composite laminate with a cork thermal shield *Compos. Sci. Technol.* **67** 3491
- [3] Hill M D 2007 *Damage resistance and tolerance investigation of carbon / epoxy skinned honeycomb sandwich panels* (Leicestershire: Michelle Hill) p 390
- [4] Zhou G and Hill M 2007 Damage characteristics and residual compressive strength of composite honeycomb sandwich panels (16th International conference on composite materials)