# A STUDY ON RESIDUAL STRENGTH OF AL HONEYCOMB CORE SANDWICH COMPOSITE PANEL AFTER QUASI-STATIC INDENTATION DAMAGE

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## ABSTRACT

This study aims to investigate the residual strength of sandwich composites with Al honeycomb core and carbon fiber face sheets subjected to the quasi-static indentation damage by the experimental investigation. The 3-point bending test and the edge-wise compressive strength test were used to find the mechanical properties, and the quasi-static point load was applied to introduce the simulated damage on the specimen. The damaged specimens were finally assessed by the 3-point bending test and the compressive strength test. The investigation results revealed the residual strength of the damaged specimens due to the quasi-static indentation.

## 1. INTRODUCTION

Recently, lots of studies on light weight composite structures, especially sandwich composite structures due to their great advantages have been done for the advanced transportation systems. Among them the Al honeycomb sandwich type structure has been adopted to improve the lightness and the structural stability of the primary structure for aircrafts and spacecrafts. However this sandwich composite structure is very weak against impact damages. Especially the damages due to the low velocity impact rather than that by the high velocity impact cannot be easily found. Many researchers have studied structural behaviours on the sandwich honeycomb structure damage using a dropped- weight impact test[1] or quasi static indentation test[2].

In this study, investigation on residual strength of honeycomb sandwich composite structure due to damage was performed. The sandwich composite panels and Al honeycomb core were co-cured by autoclave and then quasi-static indentation tests were performed to understand of deformation and fracture responses of composite sandwich plate. It was classified three steps to estimate residual strength of specimens after damage, Case 1 exhibits the early stage of the indentation process when the Al honeycomb core starts to yield; Case 2 corresponds to deeper indentation depths when both the skin and the core yield; Case 3 presents cracked skin with crushed Al honeycomb core. The 3-point bending test and the edge-wise compressive strength test was performed about three cases.

## 2. MATERIAL AND MANUFACTURING PROCESS

The sandwich composite panels with the laminate UD carbon fiber face sheets (HT145/RS1222, HANKUK FIBER CO., LTD) and Al honeycomb core (Al-3/8-5052, HANKUK FIBER CO., LTD) were co-cured by a small scale autoclave (see Fig. 1). Laminated sequence was [0°/90°/0°/90°/core/90°/0°/90°/0°]. The sandwich composite were fabricated by Al honeycomb core of 10 mm thickness. The sandwich panels were firstly cured at 127°C and 2.5bar for 150minutes. An Epoxy adhesive film (Bondex 206, HANKUK FIBER CO., LTD) was applied at the interface between the face sheets and the Al honeycomb core to ensure good bonded faces. Figure 1 shows the manufacturing process of the sandwich honeycomb panel.

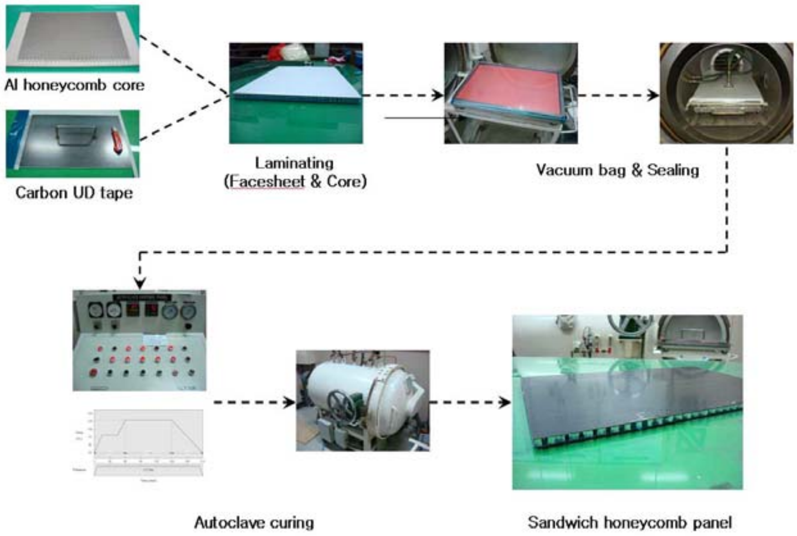



Figure 1: Co-curing process flow of Al honeycomb sandwich panel

## 3. EXPEREMENTAL TEST RESULTS

### 3.1 Three-point bending test and compressive test before quasi-static indentation

An experimental test set-up for the 3-point bending test and the compressive test were applied for loading by the universal testing machine (100KN, RIGER CO.). The residual strength of specimens were assessed by the 3-point bending tests according to ASTM C393, D790[4, 5]. The specimen of the 3-point bending test had a length of 192mm and a width of 50mm. The compressive strength test of specimens was also performed according to ASTM C364, C365[6, 7]. The specimen of compressive test had the length of 70mm and the width of 70mm. Figure 2 and 3 show schematic diagrams of the 3-point bending test and the compressive test. Displacement speed was placed at 0.5mm/min.

The specimen results after the 3-point bending test is illustrated as Fig. 4. Middle core deflection of specimen after linear elastic deformation increased. The strength of core rapidly decreased after linear elastic deformation according to increase in bending load. The load–deflection curve decreased to a load of 1523.8N. Finally, face sheet and core by compressive load was permanently deformed. The result of the compressive test is shown in Fig. 5. The face sheet of specimen was fractured due to increase of compressive load. The load–displacement curve decreased to a load of 32.6kN. The specimen had bending deformation and then the load rapidly decreased.

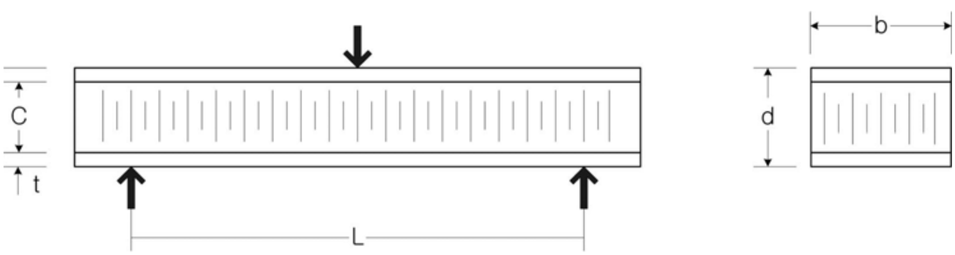



Figure 2: Schematic diagram of 3-point bending test

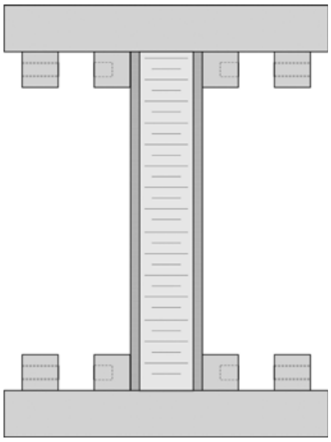


Figure 3: Schematic diagram of compressive test

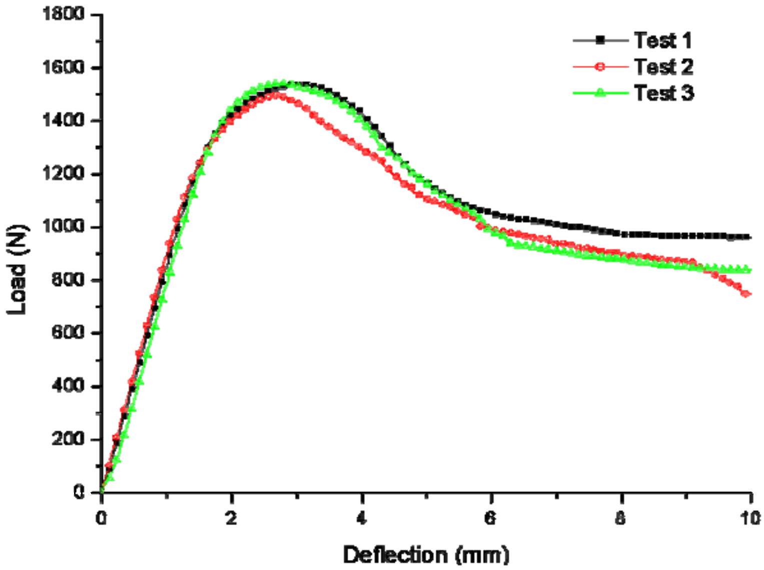



Figure 4: Load-deflection curves by 3-point bending tests

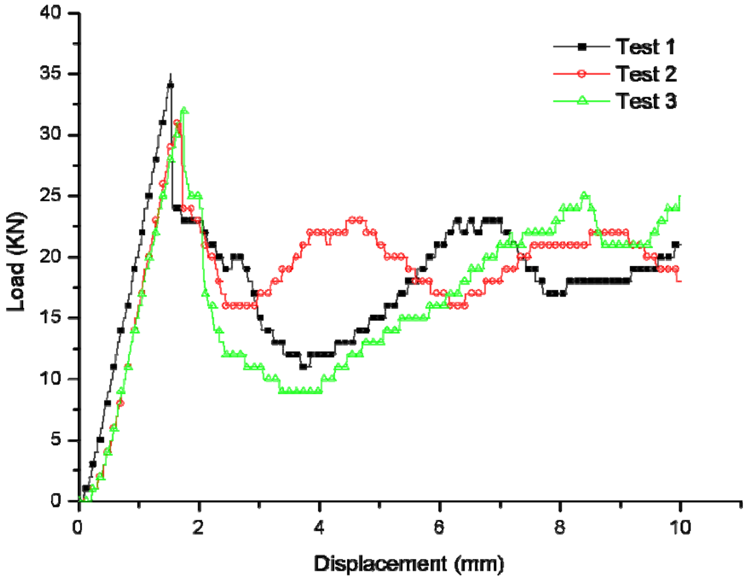



Figure 5: Load-displacement curves by compression tests

### 3.2 Quasi-static indentation test

In this study, the quasi-static indentation test was performed for residual strength investigation of the damaged specimen. An experimental test set-up for the quasi static indentation is shown in Fig. 6. A hemispherical steel indenter with the diameter of 10mm was chosen for loading by the universal testing machine and the quasi-static point load was applied at the center of the specimen in order to introduce the simulated damage. The specimen size was same as the undamaged specimen.

The quasi-static indentation load was applied on a face sheet surface of the sandwich panel with different indentation depths. A typical load-indentation curve in the quasi-static indentation loading is shown in Fig. 7. As shown in Fig. 7, the curve divided into three regions: Case 1 region exhibits the early stage in the indentation process when Al honeycomb core starts to yield; Case 2 region corresponds to the deeper indentation depths when both the face sheet and the core yield; Case 3 region presents the cracked face sheet with the crushed Al honeycomb core. Figure 8 shows the cutting section of indented specimens.

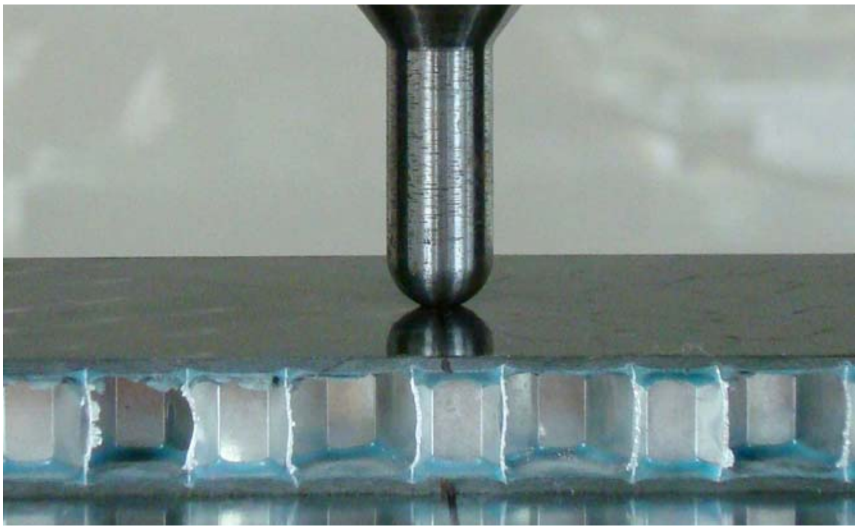


Figure 6: Quasi-static indentation test using UTM

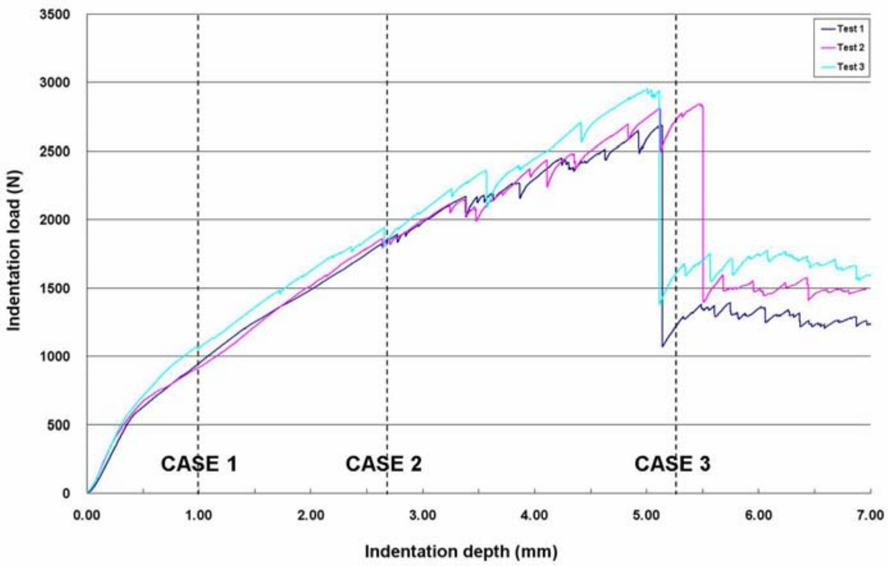
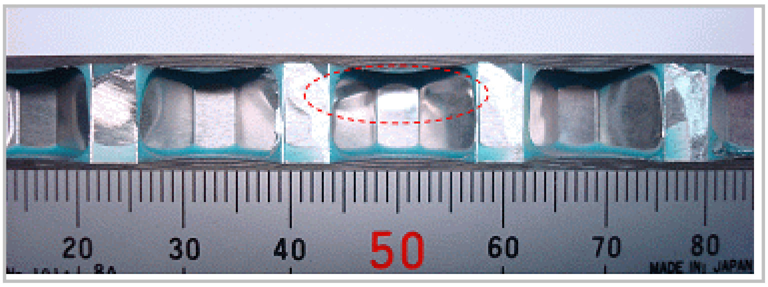
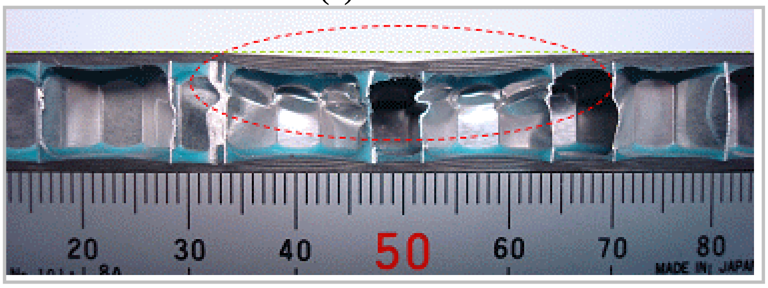


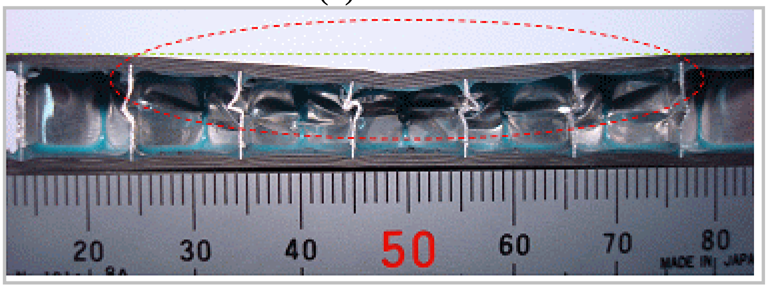

Figure 7: Load-indentation depth of the quasi-static indentation




(a) Case 1




(b) Case 2




(c) Case 3

Figure 8: Cutting section of the indented specimen

### 3.3 Comparison between undamaged and damaged specimen test

The residual strengths of both the undamaged and damaged specimens were assessed by the 3-point bending tests according to ASTM C393, D790. The edge-wise compressive strength test of both the undamaged and damaged specimens was also performed according to ASTM C364, C365.

From the 3-point bending test results after the quasi-static indentation(see table 1), it was found that both the tensile and compressive residual strength of the damaged specimen with 1mm depth slightly increased. The reason why the residual strength was slightly increased even though the specimen was damaged due to contribution of core residual stress by the indentation[3]. However the residual strength of the damaged specimens having depths larger than 1mm was rapidly decreased. In the case 2, the tensile strength decreased by 4.7% and compressive strength decreased by 5.1% than the undamaged specimen. In the case 3, the tensile strength decreased by 22.3% and compressive strength decreased by 28.3% than the undamaged specimen. From the compressive strength test results after the quasi-static indentation(see table 2), it was also found that the residual strength decreased according to increases of the damaged depth from 1mm to 5.25mm. In the case 1, the test results are similar to those of the undamaged specimen. In the case 2, compressive strength decreased by 46.1% of the undamaged specimen. In the case 3, compressive strength decreased by 62.7% than the undamaged specimen.

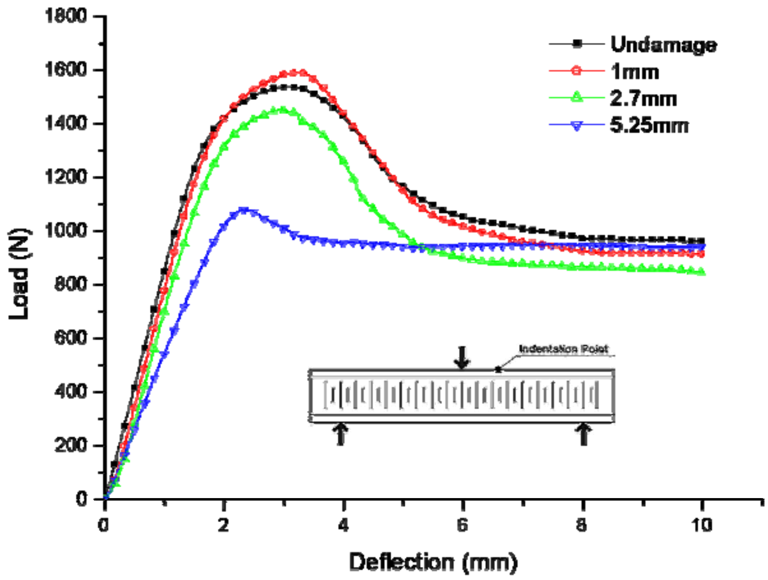



Figure 9: Load-deflection curves by 3-point bending tests

Table 1: Comparison for each cases test results on 3-point bending

| | | Undamaged | Indentation depth | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1mm | | 2.7mm | | 5.25mm | |
| | | | Ten. | Comp. | Ten. | Comp. | Ten. | Comp. |
| Max. Load (kN) | Spec. 1 | 1534.0 | 1653.5 | 1585.2 | 1414.6 | 1454.8 | 1195.0 | 1185.4 |
| | Spec. 2 | 1497.3 | 1559.5 | 1628.8 | 1462 | 1419.3 | 1248.9 | 1012.8 |
| | Spec. 3 | 1540.2 | 1554.6 | 1591.5 | 1477.8 | 1462.9 | 1107.8 | 1080.6 |
| Aver. | | 1523.8 | 1589.2 | 1601.8 | 1452.2 | 1445.7 | 1183.9 | 1092.9 |
| Rate(%) | | 0.0 | 4.3 | 5.1 | -4.7 | -5.1 | -22.3 | -28.3 |

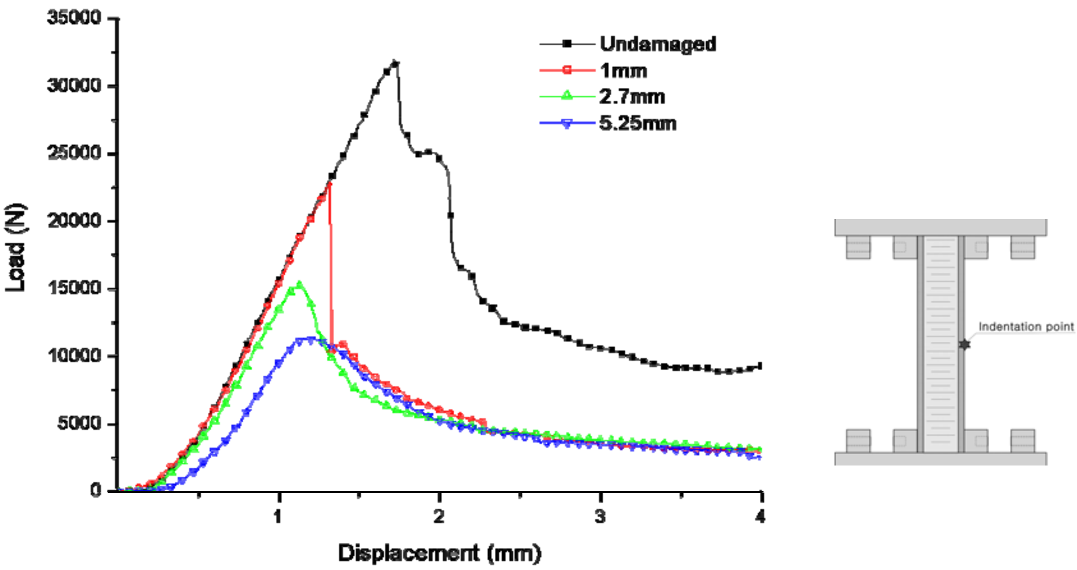


Figure 10: Load-displacement curves by compressive tests

Table 2: Comparison for each cases test results on compressive test

| | | Undamaged | Indentation depth | | |
|---|---|---|---|---|---|
| | | | 1mm | 2.7mm | 5.25mm |
| Max. Load (kN) | Spec. 1 | 31.9 | 22.9 | 15.2 | 15.0 |
| | Spec. 2 | 31.2 | 22.3 | 15.2 | 11.3 |
| | Spec. 3 | 34.8 | 28.4 | 22.4 | 10.1 |
| Aver. | | 32.6 | 24.6 | 17.6 | 12.1 |
| Rate(%) | | 100.0 | -24.7 | -46.1 | -62.7 |

## 4. CONCLUSIONS

This study is to investigate the residual strength of a sandwich panel with Al honeycomb core and carbon fiber face sheets. The quasi-static point indentation load was applied to the specimen to introduce simulated damage, and the 3-point bending test and the edge-wise compressive strength test was performed to find the residual strength. Both test results showed that the residual strength of the damaged specimen decreased according to increases of the damaged depth. The depth of the indentation zone greatly affects the strength reduction in bending and compression.


## ACKNOWLEDGEMENTS

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6- ASTM C364 : Standard Test Method for Edgewise Compressive Strength of Sandwich Constructions.
7- ASTM C365 : Standard Test Method for Flatwise Compressive Strength of Sandwich Constructions.