

# Experimental study of low-velocity impact on foam-filled Kraft paper honeycomb structure

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**Abstract.** Low-velocity impact tests of unfilled and foam-filled Kraft paper honeycomb are carried out to investigate the effect of foam, indenter size and location of indentation on maximum or peak force and energy absorption capability. In this study, three indenter sizes (10mm, 12mm, 15mm) and three different locations of indentation (vertical edge, double wall and single wall) were used and compared. The test results show that the foam is given a significant increment of peak force and specific energy absorption to the honeycomb structure subjected to indentation load. The peak force and energy absorption capability also effected by indenter size which due to the contact area of indentation. As for the location of indentation, vertical edge gives highest peak force and energy absorption by the fact that vertical edge is the intersection of three walls of honeycomb cell.

## 1. Introduction

Honeycomb core has been extensively used in energy absorbing application since they are relatively low weight and high energy absorbing capability. However, one of the main concern is the fact that the honeycomb structure are susceptible to indentation failure due to localized loading [1]. The load-carrying capability of the structure significantly reduced by the presence of the damage which can lead to a decrease of the structure strength by 50%. Hence, it is important to make a good understanding of the indentation response on the honeycomb structure. Castanie et al. [2] studied the core crush criterion to determine the residual strength of impacted sandwich structure using finite element analysis. Meanwhile Aminanda et al. [3] investigated the crushing mechanism of honeycomb structure and found that the cell wall buckled very quickly and the failure of the honeycomb due to the folding of the cell wall. In order to overcome this problem, a number of work has been carried out on the effect of foam as a filler to hollow core [4–9]. As results, they found that filling the low-density foam inside the cell has strengthened the cell wall and enhanced the energy absorption capability and damping properties of the structure. Besides, the mean crushing strength and energy absorption capability of foam filled structure are greater than the summation of the individual component [8,9]. However, most of the previous works focused on the uniform compression loading, and least research work on low-velocity impact or indentation test on foam-filled structure. Also, low-velocity impact is considered as the first step of study prior to the higher velocity impact.

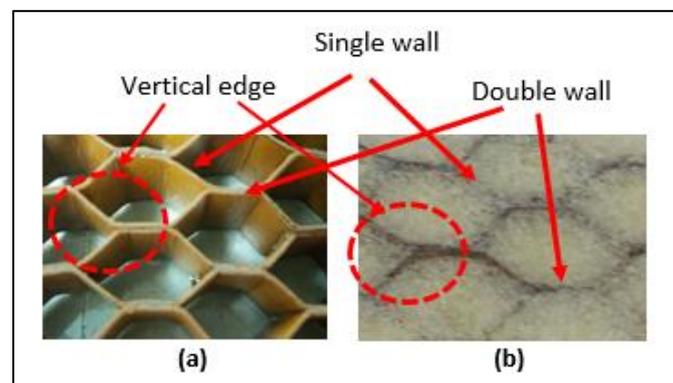
In this work, low-velocity impact tests are conducted on foam-filled Kraft paper honeycomb to investigate the influence of foam as a filler in Kraft paper honeycomb. Then, the effect of indenter size and indentation location on the peak forces and energy absorption capability of foam-filled structure



were studied. The deformation and failure mechanism of unfilled and foam-filled Kraft paper honeycomb are observed and described as well.

## 2. Experiment materials and methods

The Kraft paper honeycombs are fabricated from commercial Kraft by using handmade honeycomb maker. They are coated with vanish and cured at room temperature for 24 hours. Polyurethane foam with density of  $52 \text{ kg/m}^3$  are used as filler in the Kraft paper honeycomb structure. It is made by mixing of polyol and isocyanate in liquid foam with ratio 110:100. The mixer was poured inside the honeycomb cells until its blow and left for 24 hours to harden. Then, the indentation tests are carried out on foam, unfilled honeycomb and foam-filled specimen. The bottom surface of specimen is fixed and the upper surface are subjected to indentation loading using spherical indenter with diameter,  $d = 10\text{mm}$ ,  $12\text{mm}$ ,  $15\text{mm}$  and with speed  $2\text{mm/min}$ . Three different locations of indentation are identified; vertical edge, double wall and single wall as shown in figure 1. The force-displacements curves are plotted for further analysis.



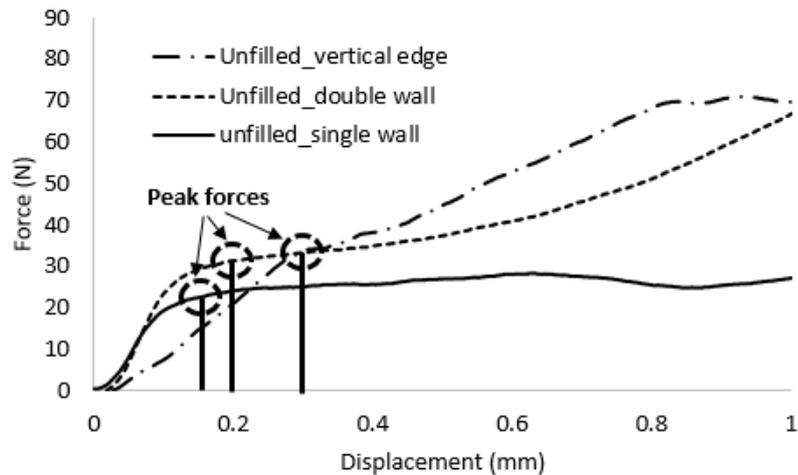
**Figure 1.** The location of vertical edge (VE), double wall (DB) and single wall (SW) for a) unfilled and b) foam filled Kraft paper honeycomb.

## 3. Results and Discussion

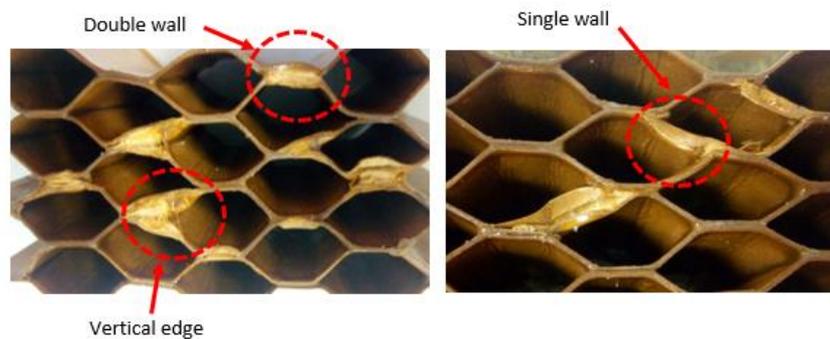
### 3.1 Unfilled Kraft paper honeycomb

A sample of force-displacement curves of unfilled Kraft paper honeycomb after indented with 10mm diameter size of indenter at three different location (vertical edge, double wall, single wall) are shown in figure 2. It can be observed that unfilled Kraft paper honeycomb exhibited nonlinear behavior for all locations and the curves demonstrate the same features where the force initially increases linearly until its peak force which corresponds to the maximum force needed to create the first folding of crushed cell wall. After initial folding of the cell wall, the force remains constant over the plateau which corresponds to the succession of fold. The plateau is importance for energy absorption capability calculation and the length of the plateau depend on the location of the indentation.

The peak force for vertical edge is the highest followed by double wall and single wall. The deformation of unfilled Kraft paper honeycomb at different locations can be observed in figure 3. It can be seen that the unfilled Kraft paper honeycomb collapse due to the folding of the cell wall. The single wall and double wall shows the same fold shape compared to vertical edge which indicates tearing or opening phenomenon. The tearing is due to the fact that vertical edge is formed by the intersection of three cell walls which lead to the increment of buckling strength and therefore the peak force. Vertical edge also behaves as a stiffener in Kraft paper honeycomb which has been discussed by Castanie et al. [3] and Aminanda et al. [10] in their works.



**Figure 2.** Force-displacement curves of unfilled Kraft paper honeycomb at different location subjected to indentation with diameter of indenter  $d=10\text{mm}$ .

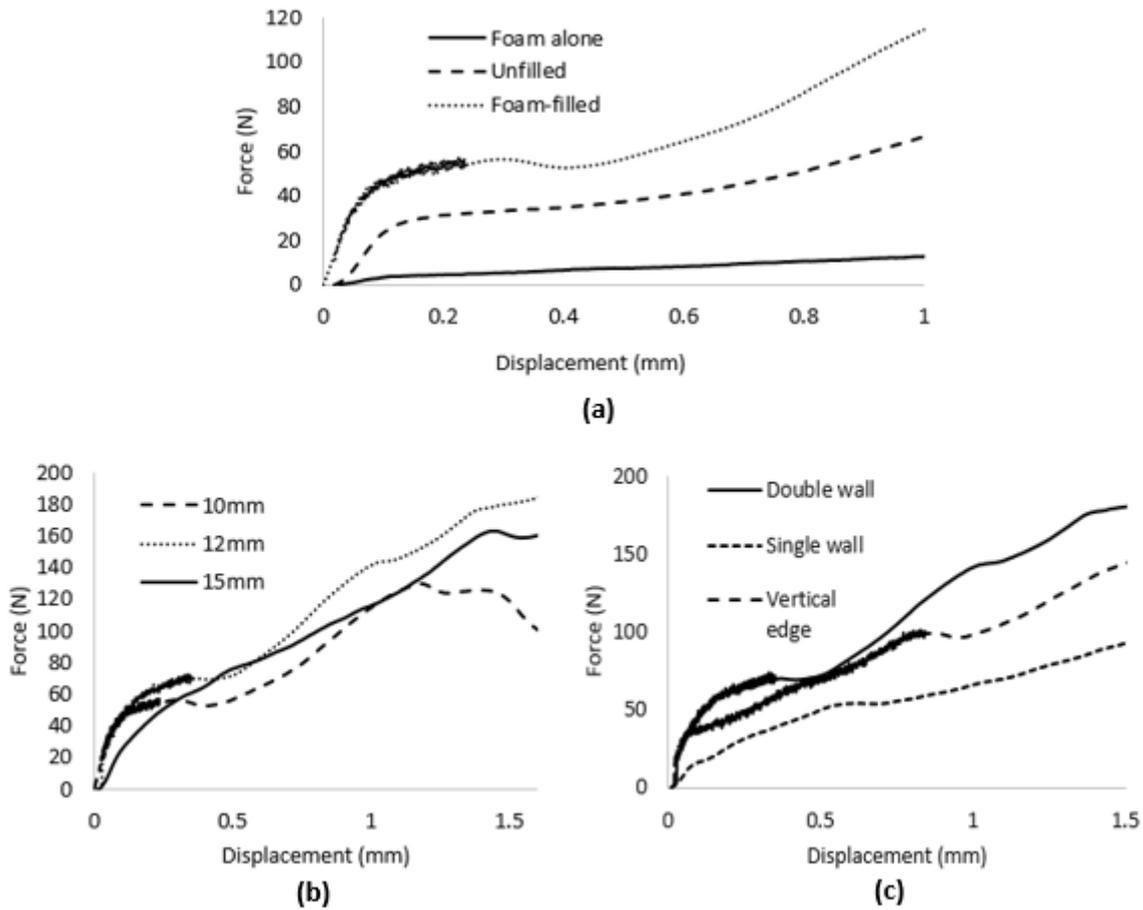


**Figure 3.** Condition of unfilled Kraft paper honeycomb after indentation.

### 3.2 Foam-filled Kraft paper honeycomb structure

Using the same parameters, the force in function of indentation displacement for unfilled, foam alone and foam-filled and using different indenter size and indented at different location are drawn in figure 4. From figure 4 (a), the curve shows a nonlinear behavior for all specimens. The peak force of foam-filled is higher than the additional of foam and unfilled one which shows the effect of foam in increasing significantly the peak force and energy absorption capability. Figure 4 (b) shows the effect of indenter sizes on the force of foam-filled Kraft paper honeycomb where 15mm indenter size exhibited higher peak force followed by 12mm and 10mm indenter size. Figure 4 (c) shows the force magnitude depending on the locations of indentation.

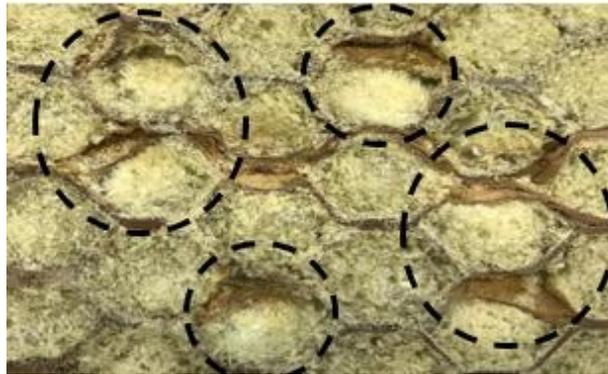
Table 1 represent the comparison of peak forces and energy absorption for different parameters mentioned previously. The energy absorption is calculated from the area under the force-displacement curve up to maximum indentation which is the radius of indenter. The table show that, the peak force and energy absorption of foam-filled honeycomb are always higher than unfilled and foam alone. Based on the failure mechanism of foam-filled specimen (figure 5), the foam filling up the folded wall which increases the buckling strength of walls. From table 1 and figure 6, it can be observed as well that higher indenter diameter resulting higher peak force and energy absorption. From damage area observation, higher diameter creates bigger indentation contact area, hence increases the peak force and energy absorption.



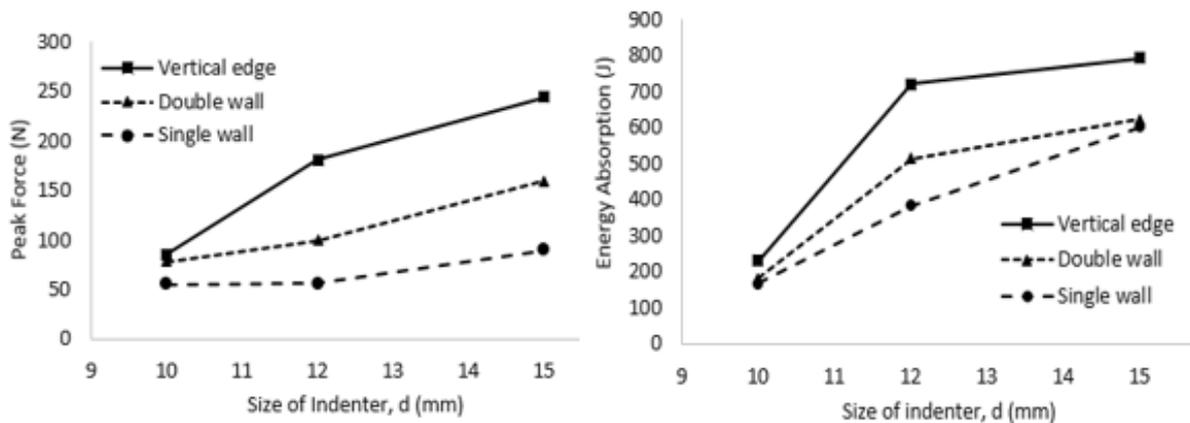
**Figure 4.** Force-displacement curves of a) foam-filled, unfilled and foam alone at different location b) foam-filled at different indenter size c) foam-filled at different location of indentation.

**Table 1.** Comparison of peak forces between foam filled paper honeycombs, unfilled and foam alone with three different indenter size and location.

	Peak Force (N)					Energy Absorption (J)				
	Foam	unfilled	Foam-filled			Foam	unfilled	Foam-filled		
			10mm	12mm	15mm			10mm	12mm	15mm
Vertical edge		33.6	85.7	181	244	7.3	43	230	720	792
Double wall	3.1	32.5	77.9	99.2	159		38	180	514	622
Single wall		24.8	54.6	55.7	89.5		24	167	383	603



**Figure 5.** The deformation of foam-filled Kraft paper honeycomb after indentation test.



**Figure 6.** Peak forces and energy absorptions of foam foam-filled Kraft paper honeycomb for different indenter size and location of indentation.

#### 4. Conclusion

Low-velocity impact tests are carried out to study the peak forces and energy absorption performances of Kraft paper honeycomb. The results showed that foam-filled Kraft paper honeycomb exhibited high peak force and energy absorption compared to unfilled and foam alone due to the strengthened of cell wall by foam as a filler. Then, the effect of indenter size and location of indentation were discussed. Bigger indenter size is prone to increasing the peak force and energy absorption capability due to large indentation area. Meanwhile, the indentation at vertical edge gives higher peak force value and energy absorption compared to double wall and single wall due to the indentation area of the Kraft paper honeycomb which increase the resistance to buckling.

#### Acknowledgements

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