EMPTY ALUMINIUM HONEYCOMB UNDER QUASI-STATIC LOADING: EXPERIMENT AND SIMULATION

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ABSTRACT: In recent years, study involving aluminium honeycomb has grown rapidly. This is due to the properties of aluminium honeycomb that are very useful in energy absorbing area. This paper focuses on compressing the aluminium honeycomb in all directions; in-plane and out-of-plane direction for both experimental and simulation work. It is found that compression in out-of-plane direction offered far superior energy absorbing characteristic compared to the in-plane directions. Factor that contributes to this difference is found to be the imperfection of the aluminium honeycomb itself. All honeycomb deformed dissimilarly base on the stiffness and direction of compression.

KEYWORDS: *Honeycomb Structure; In-Plane Compression; Out-Of-Plane Compression*

1.0 INTRODUCTION

Metallic honeycomb especially aluminium honeycomb has become popular in recent years. The rapid growth of interest in this material has been due to the good characteristics of the material itself such as high stiffness to weight ratio and high value for specific energy absorption. Based on this advantages, researchers has chosen aluminium honeycomb to study their ability in energy absorbing application in which it will act as a core or filler element [1] . The honeycomb can be compressed in two directions; in-plane and out-of-plane direction. In the in-plane direction, extensive experimental investigations were performed [2-6] and focused on many aspects on the crushing of the honeycomb. Hu in [4-6] and Deqiang [11] studied on the deformation mode of the honeycomb. Their findings showed that, honeycomb subjected to low velocity impact will produce an 'X' and inversed 'V' shaped deformation type. In contrast, when the structure experienced high velocity impact, the crushing band began at the loading edge and progressively propagates layer by layer.

Papka [2] investigated that the evaluation of the material mechanical properties such as cell wall size to thickness ratio, yield stress and strain hardening can be done under a simple collapse analysis. Besides, the study discovered that the imperfection of the cellular structure happens during the manufacturing process of the honeycomb. The geometrical defects of the honeycomb (at the corners) are usually rounded and the distance between corners in the ribbon direction is less than the perfect honeycomb. The two factors that lead to this problem were inaccurate bond line length with the cells and over/under-expanded cells.

Researchers in [7-12] have explored on the honeycomb with filler element using the FE simulation. The work covered the lateral crushing of regular, irregular and functionally graded honeycomb. Missing cluster is one of the forms of irregularities of a honeycomb [7]. The energy absorption recorded at the early stage is affected by this missing cluster that closer to the rigid plate, yet holistically this type of irregularity does not have significant effect on the energy absorption of the material.

In-plane loading can be executed in two directions; across corners and across faces of the cellular structure. Said [8] found that the collapse load of the honeycomb in the across corner direction is 50% greater than in across faces direction. Deqiang [11] performed the compression in the across faces direction subjected under high velocity impact and low velocity impact. It is observed that 'I'-shaped bands is produced during the high velocity impact, while an 'X'-

shaped bands is produced during the low velocity impact. In addition, 'V'-shaped band occurs when moderate velocity impact is applied. However, only the 'V'-shaped and 'I'-shaped were captured in the study. Particularly, the 'V'-shaped initiated at low velocity impact, whereas the 'I'-shaped initiated under the moderate and high velocity impact.

In the out-of plane research area, McFarland [16] introduced the model to predict the strength of hexagonal honeycomb. The model was later improved by Wierzbicki [17] in which the model could also be used to determine the plateau stress for the structures. Recently, Zhang et al. [18] used SFE (Super Folding Element) to predict the crushing strength of honeycombs by using basic constitutive angle element namely Y-shaped, T-shaped and X-shaped. The honeycomb tested was in the shape of square, hexagonal, rhombic and Kagome. In addition for the Y-shaped modelling, Yamashita [19] used the modelling setup to represent a quarter part of one cell honeycomb. The expending angle used were varies from 30° to 150°. According to Levent [20], there are two types modelling method in honeycomb structure which are known as micromechanical modelling and homogenized finite element model which is commonly used in SAC (Semi-adaptive Numerical Coupling) technique. The first modelling method hold the advantage in representing the buckling mode of the honeycomb structure in full scale mode, while the latter has the ability to model the model compaction during the crushing of larger model as the discrete particles are introduced.

This paper aims to study deforming mode as well as the energy absorption capabilities of empty honeycomb compressed in quasi-static condition. The experimental result will then be validated by using Finite Element Analysis.

2.0 METHODOLOGY

2.1 Experimental Setup

Aluminium honeycomb (Al-3003 H18) is used in this investigation. The yield stress, young Modulus and Poisson ratio were found to be 115.8 MPa, 69 GPa and 0.33 respectively. Table 1 shows the parameters of the materials and the size of the honeycomb was fixed at 42 cells (6x7). All honeycombs were compressed in three directions as illustrated in Figure 1 by using Instron machine with quasi-static speed of 5mm/min.

Table 1 : The parameters of Aluminium Honeycomb

Parameter	Values
Cell size, c	6.35 mm
Thickness, t	7 µm
Length, l	100 mm
Width, w	90 mm
Height, h	85 mm
Mass of empty honeycomb	0.0294 kg

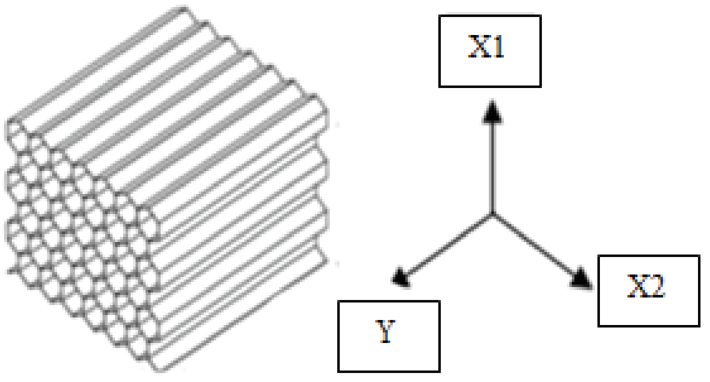

Figure 1 : Direction of compression

2.2 Finite Element Analysis Setup

ABAQUS 2016 was used to simulate the experimental work. The honeycomb model size was drawn according to the actual size of the honeycomb sample. As shown in Figure 2, two rigid plates are placed on top and bottom of the shell element honeycomb. In order to ensure that the bottom plate is fixed while the top plate is in velocity-based condition, the boundary condition was set to each plate; encastre for the bottom plate and one-axis velocity for the top plate. The mesh size for the honeycomb model and the plate model were set to be 0.001mm and 1mm correspondingly. The model is then crushed with the same speed as the experimental setup and the crushing behavior for all cases was observed. The number of elements for the simulation setup was 153002 while the number of nodes was 150399.

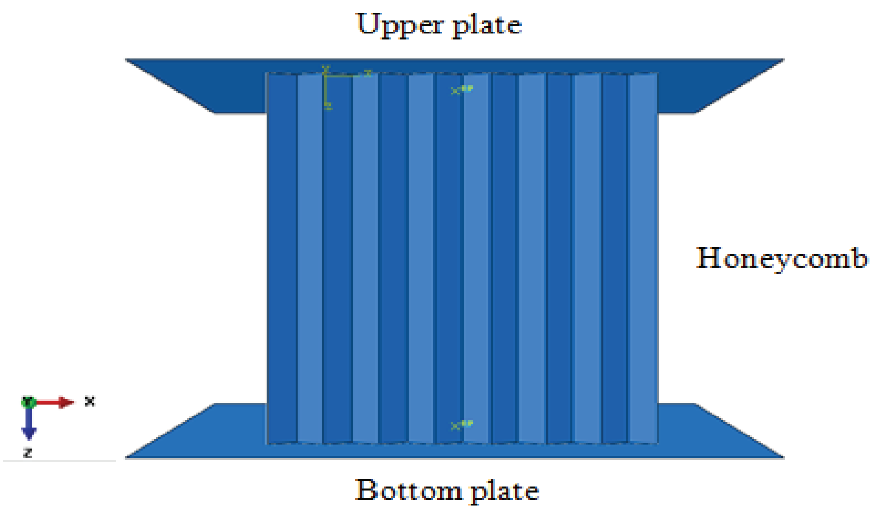

Figure 2 : Illustration of simulation setup

3.0 RESULTS AND DISCUSSION

3.1 Y-directional Compression

For the compression in Y direction, the specimen undergoes local buckling in which is initiated at the top part (near the loading region) of the specimen. The buckling is then continued to develop in the same pattern until the specimen is fully compressed.

3.2 X-directional Compression

In the X1 direction, it is observed that the collapse mode of the honeycomb was initiated at the top-left and then the band propagated to the bottom-right part of the specimen. After that, the nearby cells which were weaken by the band started to collapse progressively following the initial crushing band. For the X2 direction, the collapse mode was started at the middle part of the specimen. The band was initiated at the left side and then it propagated to the opposite side. After the middle part was fully deformed, the band spreads to the nearby cells causing them to collapse gradually. For both specimens, they undergoes three stages in the in-plane crushing; linear elastic, plateau and densification stage.

Based on Table 2, it is found that specimen compressed in Y direction has the highest value in term of collapse load, energy absorbed and mean load. The factor that can contribute to this high value is that the specimen compressed in Y direction is stiffer compared to the other specimen setup. In automotive, lower value of peak/collapse load is preferable because it will reduce the damaging effect for the structures and passengers upon impact.

Table 2 : Energy absorbing characteristic for all specimens

Direction of compression	Collapse load (N)			Energy absorbed (N.m)			Mean load (N)		
	Exp	Sim	% Error	Exp	Sim	% Error	Exp	Sim	% Error
Y	3462	4677	35	135	113	15.9	1500	1329.4	12.8
X1	72	88	22	4.1105	5.209	26.7	45.7	43.4	5
X2	42	58	38	5.0574	5.929	17.23	67.4	49.4	26.7

Comparing the graphs in Figure 3, Figure 4 and Figure 5, the peak load only exist during compression in Y direction, while the collapse load only exist in X1 and X2 directions. The difference between peak load and collapse can be described as the honeycomb undergone buckling failure in the Y-direction whereas bending failure is sustained by the honeycomb in the X-directions.

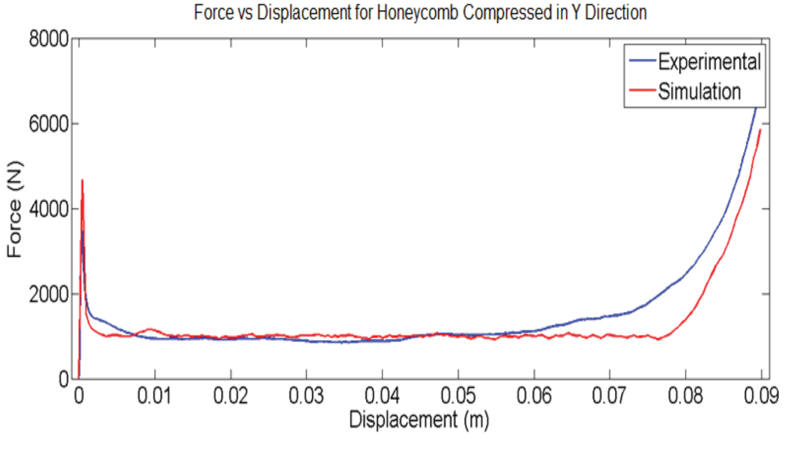

Figure 3 : Graph for compression in Y direction

While for the energy absorbed and mean load, higher value is preferred as it will stabilized the impact and later will reduce the aftereffect of the impact to both structures and passengers. The difference between experimental and simulation result is due to the imperfection in the actual specimen. In the simulation, the honeycomb is in virtual mode, which contributes greatly for the honeycomb dimensions accuracy and condition. However, the honeycomb that is being tested experimentally is not perfect due to some impurities and irregularities during the manufacturing process. In the worst-case scenario, the cells in the honeycomb are already distort/bent even before the experimental work started. This reduces the accuracy in term of dimension for the honeycomb.

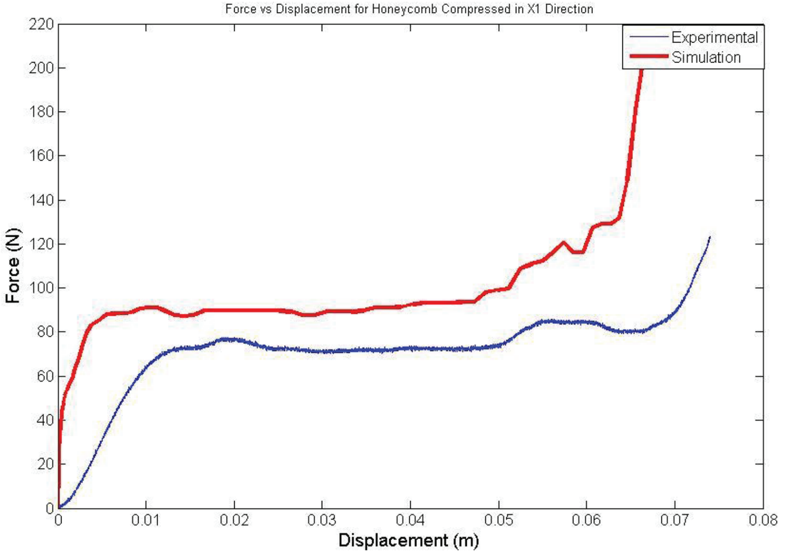

Figure 4 : Graph for compression in X1 direction

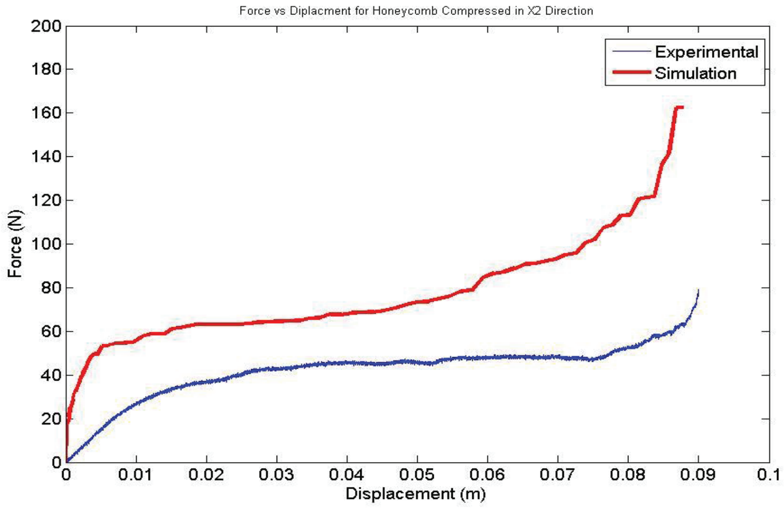

Figure 5: Graph for compression in X2 direction

4.0 CONCLUSION

As a conclusion, it is found that the honeycomb compressed in Y direction has far superior energy absorbing characteristics compared to the others. In term of deformation type, the honeycomb compressed in X1 direction undergoes deformation due to bending of cells, honeycomb compressed in X2 direction undergoes deformation due to buckling of cell and honeycomb compressed in Y direction undergoes local buckling of the structure. These three different deforming types contribute directly to the energy absorption value. Lastly, the difference between experimental and simulation work was affected by the imperfection in the actual honeycomb structures, whereas the virtual honeycomb structure in the simulation work is in very perfect conditions. In the future, an attempt to study the deformation modes and energy absorption capabilities of honeycomb with filler element can be conducted.

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