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Effect of Cell Size Material on the Mechanical Properties of Honeycomb Core Structure

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Abstract: ***A study on the effect of cell size material on the mechanical properties of honeycomb core structure was performed with different materials used; Al 6061, polypropylene and polystyrene. Drop-weight impact test and compression test on honeycomb structure core have been performed with impact test showed the results of maximum force and value of energy while the compression yield the stress-strain curve as well as failure mechanism in the structure. The experimental result shows that impact force increased with the increasing value of energy. Al 6061 honeycomb structure showed the most deformation formed compared to the thermoplastic core. Experimental compression test was conducted to analyze the mechanical behaviour of honeycomb structure core under compressive loading and from the observation the core started to buckle at the edge due to the stress loading. Al 6061 core shows permanent buckling while thermoplastic rebound back after certain amount of time.***

Keywords: materials, honeycomb, impact, compression, failure

1. Introduction

Composite materials is the most recent materials that used by people for their domestic usage. Nowadays, there were high increment of interest in composite materials in industrial fields like Carbon Fiber Reinforced Plastic (CFRP). One of the well-known composite materials is devoted to the development of the honeycomb sandwich panel [1] because of the low weight and improved mechanical properties compared to metal. Sandwich structure are wildly used in production engineering or material engineering prospect due to the very good in performance of ultra-light, have higher stiffness than the other material, strength to weight ratios, have excellent energy absorption capability and shock mitigation [2] [3] [4]. It is also one kind of typical low density cellular solids that have other attractive functionalities for example honeycomb is very good for heat transfer, thermal protection, catalysis application and also be used as energy actuators [5]. For heat transfer properties, regular hexagonal honeycomb metal provide the highest level of heat dissipation when used as heat sink media [6]. Sandwich structure material also known because of its characteristic to increase the durability and strength of the structure with its outstanding properties such as lightweight construction while the faces of the sandwich structure capable of bearing both tensile stress and compressive stress and the core will be able to bear shear stress [7]. A strong core can also contribute to the flexural stiffness and to the out of plane shear and compressive strength of the panel. On the other hand, a core with poor mechanical properties will reduce the performance of the panel [8]. Honeycomb sandwich structure panel have their own privilege because of its properties better than other material. Because of this properties, honeycomb sandwich structure panel have wildly used in marine, aerospace, transportation and automotive industries [7] [5] [9]. In aerospace, honeycomb sandwich materials have been used as secondary structural materials or interior panels [10]. Basically, honeycomb sandwich structure panel consists of three layers that is face sheets, adhesive bonds and one core. Face sheets must come from the materials that have high Young's modulus like fiber reinforced plastics or steel and aluminium composition. The center part of the sandwich structure known as core can be designed as homogenous material like foams, paper filling or as textured cores such as honeycomb. These homogenous cores are used mainly in low cost and low stressed part and on the other hand textural cores such as honeycomb can be found in part with the highest requirements related to mass and stiffness [11].

2. Literature Review

Honeycomb-like alignment from wood cell wall which consists of polysaccharides (cellulose and hemicellulose) and an aromatic polymer (lignin) were provided by Y. Uraki et al. This type of fabrication is not based on the metal based fabrication however the author proved this type of fabrication found an achievement in terms of natural mechanical properties of wood. The result of fabrication were commercially available and have wide range of applications [12]. For stocchi et al, they introduced a honeycomb core made from natural-fiber reinforced composite. The composite compose of thermoset-polymer (vinyl ester) with jute fabrics reinforced. This core were manufactured by using compression molding at laboratory scale with two molds that is mold with fixed inserts and lateral compression lateral molds. For first mold, the jute fabric were placed between the inserts following a zig-zag pattern in the ribbon direction and the results is the wall thickness of the core t = 1.43 ± 0.10mm. On the other hand, lateral compression mold consists of aluminium "combs" series with the shape of the cells which could displace laterally. The result of second technique compared with first technique, the wall thickness decrease to 1.11 ± 0.10mm. These technique of fabrication does not give same result so special care were taken by the manufacturer to duplicate the manufacturing conditions in order to obtain samples with the same thickness and fiber contents [8]. One method of fabrication were made by the aluminium core but it is not in terms of honeycomb core structure but in foam structure. It is a quite different and unique method to produce a sandwich core but it has his own specialty that is it can improve tensile and bending strength when covered with two dense metallic face plates. This method were proposed by Hangai et al in Japan [13]. For Thinh et al using a high solubility of organic solvent to facilitate the fabrication of stable honeycomb pattern thin films. This process were done by casting the PANI composite solutions under humid conditions. Honeycomb pattern films were formed by the condensation and deposition of water droplets on the solution surface through evaporative cooling. This pattern of honeycomb were characterized via transmission and scanning electron microscope [14]. For Wadley et al, they used the same type of aluminium which is 6061 series. The core constructed is not a honeycomb but it consisted of triangular cross section prismatic void with the apex of the prism alternating between the top and bottom of the panel. This core is a corrugated type and fabricated from 17.8cm diameter billets using a 300 ton, direct porthole extrusion process. The result of the panel when vertical webs at the sides of the extrusions were removed is 135.9mm wide by 133.4mm long test structure geometry after the extruded panels were solutionized, water quench and heat treated to T6 condition [15]. After fabrication, the testing were done by N. Sawal et al about effect of core thickness under Low Velocity Impact test. A few sample of sandwich structure were used with different core thickness and different material between sheet and core. The core's material is thermoplastic with 20, 30 and 40mm of thickness and 1.0mm thick aluminium as a sheet of sandwich structure. The result was shows the maximum impact force increase in the increase with core thickness. When the thickness of the core increase the amount of energy absorb increase which resulting in damage initiation across the core. Beside that on the observation during the experiment, most of the panel experience the core crushing, face sheet buckling and debonding between the face sheet and core [16]. For J. Xiong et al, the sandwich panel were tested under axial compression while the structure was consists of carbon fiber composite egg and pyramidal honeycombs core. After the experimental preparation, the result shows face wrinkling, inter-cell buckling, core shear macro-buckling, face crushing, core member crushing and core debonding were observed. On the result they conclude that the pyramidal sandwich column is better than egg honeycomb sandwich column [17]. The other experimental procedure were conducted by S. Xu et al to study about crushing behavior at a constant compressive velocity onto four types of aluminium hexagonal honeycombs. The observation of deformation patterns under quasi-static loading shows plastic buckling commonly from one of the two interfaces between the specimen and load platens. In addition the cell begin to buckle randomly in one or two with the interface layers followed by alternating buckling between the two interfaces with the finish in the middle of the specimen while plastic buckling occur in the middle region of the specimen for large cell size aluminium honeycomb. From the experimental, the conclusion was made that the deformation pattern influenced by the dimension of honeycomb [18]

3. Problem Definition

Most study have been done on the sandwich structure which consists of two layer of sheets and one core but not many studies focuses on the core analysis especially honeycomb structure core. Besides that, the thermoplastic core is rarely used for an analysis compared to the metal alloy. Since then, the information of the mechanical properties and behaviour is limited.

4. Preparation of Materials

The materials were prepared starting from the cutting of raw materials which were Al 6061, PE and PS from original dimension 300 × 600 × 10 mm into two types of dimensions which were 200 × 20 × 10 mm and 20 × 20 × 10 mm. Then the honeycomb structure was designed in the Computer Aided Design (CAD) software which is CATIA V5R21. The advantage of this software is 3 dimensional (3D) design instead of 2 dimensional (2D) design. The structure of honeycomb was designed by using hexagon shape which have six axes and 6 vertices. The angle of each vertices is 120^{o} and for every side have 4.041mm of length. The dimension of core was designed based on the test that will be conducted which is Drop-weight Impact test and Compression test. Drop-weight Impact test has dimension of 200 × 20 × 10 mm while for Compression test has dimension of 20 × 20 × 10 mm. The result of the design process was honeycomb structure core and should be same with the result of fabrication process. After the design process done, the honeycomb structure core will do the simulation of fabrication by using Computer Aided Manufacturing (CAM) software which is MASTERCAM X5. This software was able to simulate the exactly outcome of fabrication process. When the simulation successful which mean that the simulation was follow the desired shape then the next process is code generation. This code was transferred via WinDNC software and essential to run the Computer Numerical Control (CNC) milling machine for the fabrication process.

5. Fabrication of Samples

The samples were fabricated by using Computer Numerical Control (CNC) milling machine with 1000 feed rate and 3500 rpm of spindle speed. To cut the materials, end mill cutting tool of High Speed Steel (HSS) with 3.0 mm diameter was used. The sample was clamped with the vice (located inside the CNC milling machine) to make sure the sample not make any movements during the fabrication. The samples were fabricated one by one until all the materials samples become honeycomb structure core.

6. Testing Method

Two types of testing method were conducted to study the mechanical properties of honeycomb structure core which were Drop-height Impact test and Compression test.

6.1 Drop-height Impact Test

Drop-height Impact test was performed by using drop-weight impact tower with 12.5 mm diameter and 2.1 kg hemispherical steel nose indenter. This experiment was conducted by varying the height of the impact drop which are 0.2, 0.4 and 0.6 m. for each drop height, the test were repeated three times to ensure accuracy. The result of impact force were detected by Kistler 9333A Piezo-electric load cell which located just above the indenter. All the tested samples of honeycomb structure core with same cell wall thickness which is 0.5 cm were placed on two 12.5 mm diameter of stainless steel cylinder located on the movable angle support. The honeycomb structure core have 200 × 20 × 10 mm dimension.

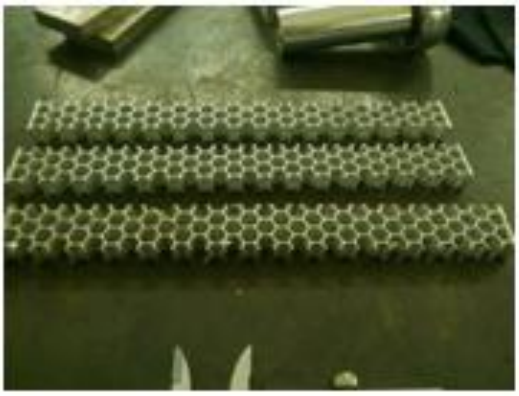

Figure 1: Samples of Drop-height Impact test specimen

Figure 2: Drop-weight Tower for Drop-height Impact test

6.2 Compression test

Compression test were conducted by using an instrumented Universal Testing Machine (UTM) with 1 mm/min crosshead speed loading. This compressive load was applied to all materials with same cell wall thickness which is 0.5 cm. The sample were placed on the floor level and below the movable crosshead. The test was carried out onto three types of honeycomb structure core materials which is Al, PE and PS until 75 % deformation before the sample totally crush. The force applied on the crosshead was 10kN to assure all the material can be deform. Then the data acquisition from respective computer were analyzed to study about honeycomb structure core mechanical properties.

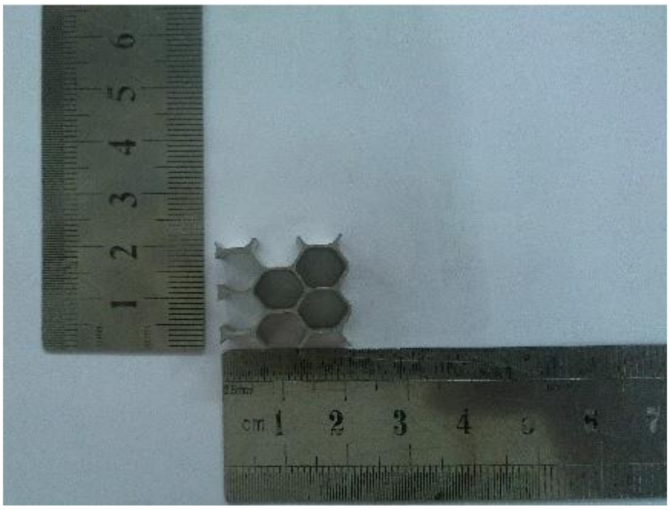

Figure 3: Sample of compression sample

Figure 4: Universal Testing Machine (UTM) for Compression Test

7. Results and Discussion

7.1 Drop-Weight Impact Test

Figure 5 the relationship of F (N) and Energy (J) for three types of honeycomb structure core which were Al 6061, PE and PS. From the figure, Al 6061 core clearly shown that it contributed high value of force meanwhile PE core shows that it have the lowest value of force for all drop height. The highest value of force was from Al 6061 core which was 162 MPa while the lowest value of force was from PE core which was 80.67 MPa. PS core shows intermediate value of force between Al 6061 core and PE core. The value of energy come from the formula which is Energy = mgh whereas m is mass which is 2.1 kg, g is gravity which is 9.81 m/s^2 and h is height. The heights are varies from 0.2, 0.4 and 0.6m. On the other hand, the value of force was directly proportional to the value of energy ($F \propto E$). When the value of energy increase the value of force also increase. All the materials core follow the pattern except for the PE core. PE core shows fluctuations result which was increase from 108.67 MPa at 4.12 J to 134.33 MPa at 8.24 J then drop until 116.33 MPa at 12.36 J. This fluctuations results is due to the several error during the experimental conducted for instance the locations of honeycomb structure core was not positioned properly on the movable point bend support. On the other hand, the fabrications process also contribute to the error during the preparation of honeycomb structure core. During the preparation, the materials sample not clamped properly and the sample have been moving a little. The consequence of this problem is when the materials sample moved, the origin positioned to fabricate the honeycomb core has been moved and become retard honeycomb structure. Retard honeycomb structure consists of cell wall thickness decrease about a few percent and the honeycomb structure not completely through the materials sample. Besides that, when the value of energy increase the deformation occur also increase or it can be says that the deformation directly proportional to the value of energy as shown in the Figure 6. When the value of energy increase the deformation become bigger. The deformation can be clearly seen at the Al 6061 core but not at the thermoplastic core which is PE and PS core. Thermoplastic core tends to come back to its original shape because of the elasticity properties.

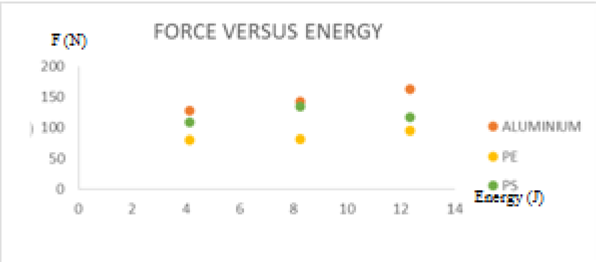

Figure 5: Graph for LVI test

(1) (2) (3)

Figure 6: Results of three different materials after impact of energy with different height from 0.2m, 0.4m and 0.6m (1) Aluminium 6061 (2) Polyethylene (3) Polystyrene

7.2 Compression test

Figure 7 shows the relationship of stress (MPa) and strain for three types of honeycomb structure core which were Al 6061, PE and PS. Highest value of stress contributed by Al 6061 core with 3.15 MPa while thermoplastic shows low value of stress which are 0.26 MPa for PE and 0.27 MPa for PS. The behaviour of the graph can be explained by using the samples results. The early part of the figure, it shows linearly increase because of the cell wall materials deformed linearly until it reach the maximum stress. At this maximum stress, the sample starts to experience buckling at the edge due to the stress loading[19][18]. After the maximum stress, the value of stress will decrease due to the increase of strain. In addition, the figure shows large differences of stress value between Al 6061 core and thermoplastic core. This is because Al 6061 core come from precipitation hardening alloy with heat treatment of T6[20] besides it have high value of yield stress while thermoplastic core have low value of yield stress. It shows that thermoplastic deform at low value of stress. Figure 8 below shows the result of honeycomb core structure after the test was carried out. Al 6061 core still in the same condition after the test done while for thermoplastic core, it can be found that these type of material can be rebound back after contain amount of time. This is due to the material properties of thermoplastic which has low value of yield strength compared to the Al 6061.

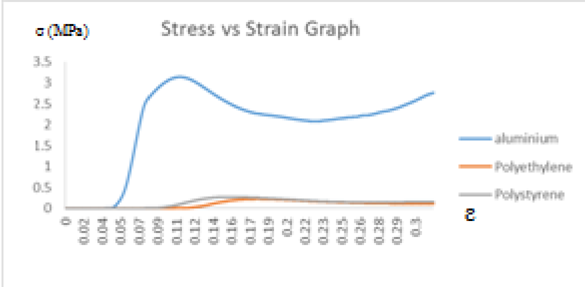

Figure 7: Graph for Compression test

a b c

Figure 8: Results of three different materials after compressive loading. (1) Aluminium 6061 (2) Polyethylene (3) Polystyrene

8. Conclusions

The effect of cell wall material were studied by fabricating the honeycomb core structure by using three different materials which are one metal alloy element and two thermoplastic. Metal alloy used in the fabrication is Aluminium 6061 while thermoplastic used are Polyethylene and Polystyrene. The fabrication of the core maintained the cell wall thickness which is 0.5 m for all materials and samples. To study the mechanical properties of these core, two tests were conducted which are Drop-weight Impact test and Compression test. From the test, the behaviour of the cell wall materials can clearly be observed that Al 6061 have the highest value of stress and force for both testing while thermoplastic shows the lowest value. In addition, Al 6061 face the high deformation and buckling compared to the thermoplastic materials.

9. Future Scope

There are various testing can be made on the honeycomb structure core with difference of cell wall material. On test that can be done during next experiment is tensile and flexural test. These two types of testing can be done to analyze the properties of the cell wall material and more observation can be seen. These two testing supposedly can be done on Universal Testing Machine (UTM) but in this project involved the fabrication process which took very long time especially when using Computer Numerical Control (CNC) milling machine. Then only one test have been accomplished which is Compression test. In addition for future study, include various more types of material to construct the cell wall material and varies the cell wall thickness. A lot of information can be gain on that.

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