

Flexural and Out-of-Plane Compression Performance of Hexagonal Rubber Wood Core Sandwich with Increasing Cell Wall Thickness

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This paper investigates the rubber wood honeycomb core by manipulating its cell wall thickness. Rubber wood honeycomb core was fabricated with cell walls range from 1 mm to 3 mm. The impacts of the cell geometrical parameters on the flexural and out-of-plane compression performance are studied. In the case of solid rubber wood without facesheet, the density is much higher than those rubber wood honeycomb composites. The failure can be disastrous without facesheet under bending. Rubber wood honeycomb sandwiches are able to offer the similar specific flexural strength with lower density. With increasing wall thickness from 1 mm to 3 mm, the specific flexural strength increased by 12.32 %. Meanwhile, specific compressive strength improved by 11 % from 1 mm to 2 mm. However, its specific strength dropped by 3.55 % when the wall thickness at 3 mm. Minimum improvement in the compressive strength per density has caused the decrement.

Keywords: Flexural, Honeycomb Sandwich, Rubber Wood, Wall Thickness, Wooden Core.

1 Introduction

Honeycomb is a cellular structure where the design is taken from honey beehives originally. The shapes of the cells are hexagonal, but other designs such as square and rectangular are available too. Honeycomb cellular structures consisting of neatly arranged thick cells that are separated by thin walls to form a planar structure. Through the advancement in engineering and technology, they can be made into many materials depending on the specification and requirement. They can be manufactured from metal, polymer as well as ceramic and are suitable to be used as core material in the composites [1]–[4].

Due to the very highly porous design with many voids, they are often applied in the engineering fields

such as automobiles, aerospace, marine and other applications that required light weight yet strong load supporting structures [5]–[7]. The porosity makes up a large volume in the structure that enable the honeycomb core to impart lightweight with high strength properties besides having good insulation properties. Moreover, the honeycombs have a planar structure that is perfect to support out-of-plane compressive and flexure stress within the component [8]–[11].

With the demand of using green and renewable resources as materials in the engineering as conservation to the environment, researchers around the globe focus on developing new materials via different parts of plants. It is to be incorporated into the manufacturing of sandwich composites to reduce the impact brought by the synthetic materials on the environment [12],

[13]. Wood core can be a good consideration for researchers because of the physic-mechanical properties of wood, biodegradability and eco-friendly nature [14]–[17].

Rubber wood or known as *Hevea brasiliensis* scientifically receives good response from the population for its milky sap called as latex. It can be used to make various items such as rubber balls, water proof clothing and home shoes. Owing to the popular acceptance of the population, natural rubber has showed up to be one of the most crucial income sources for Malaysia, Thailand and Indonesia that contribute greatly in the economy. These Southeast Asia countries contributed 97 % of world's production [18]–[20].

Latex can be tapped once the trees reach about 6 years until the tree age between 25 to 30 years. The production of latex will gradually decrease until they are regarded as economically unproductive. The cultivated rubber trees are generally smaller since the extraction of latex restricts the growth. The trees used to be chopped down and burned to prepare a fertile land for the next plantation that causes serious air pollution. It is because the trunks were considered as waste after the natural rubber is fully tapped [21], [22].

As research is getting more advanced, rubber wood in the form of lumber has been processed into packaging materials, home and office furniture [23]. Since then, the price of rubber wood is continuously soaring high due to its uniformity and light colouration not to mention its impressive mechanical properties [24], [25]. Due to large quantity of wood sawdust, flour, shaving and chips produced as a by-product, they are dumped in landfills or burned down as a quick resolution which creates further environmental pollution that affect the air quality [26], [27].

Researchers discovered that the wood by-products from the wood industry can be made into medium-density fibreboard (MDF) and particle board to minimize waste. More composite products are manufactured by combining thermoplastic or thermoset polymers in order to add value to the sawdust to become new and useful materials [28]. These composites are better as regarded as green materials that offer various attractive advantages over other synthetic materials such as low density, low cost and biodegradability besides good mechanical strength [29], [30].

The natural wood plastic composites have proven its usefulness especially the applications in the automobile such as inner panel of doors, headliners and seat backs of vehicles [31]. Besides having made into infrastructures as marina and boardwalk, products like decking, fencing and window frames in construction are available. It has been widely established into non-structural applications to replace softwood lumber for its improved durability [32]. These versatile hybrid composites are lightweight and with good impact absorption.

With the long term and steady supplies for the less functional rubber wood residual such as crown, stumps and roots from rubber tree are underutilized. Hence, a more fruitful utilization is discovered in Thailand as an important part in global warming mitigation plan for its capability to produce biomass for the electricity generation. On the contrary, the rubber wood biomass is not as common and is limited in Malaysia as other types of residual biomasses such as sugarcane stalks, rice husk and oil palm are readily available throughout the entire year [33], [34].

Furthermore, Widyarani [35] studied on the proteins from different parts of rubber trees such as latex waste, seeds and leaves. Protein extraction from rubber seeds can be processed in a bio-refinery plant for biodiesel. Meanwhile, protein gained from the leaves may be used in animal feed as bio-feedstock in the farm though available technology and knowledge. Furthermore, rubber seed contained a generous amount of crude protein that it can be utilized as edible feed and food for animals [36].

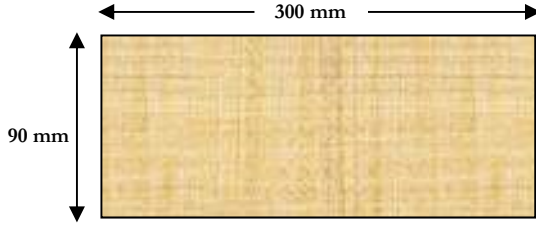
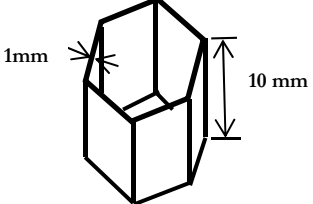
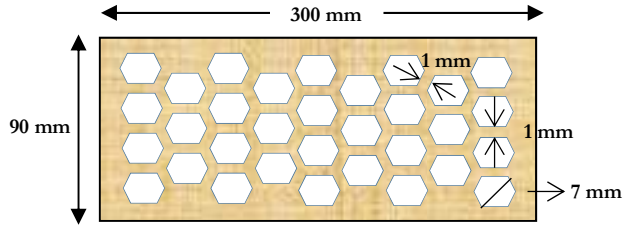
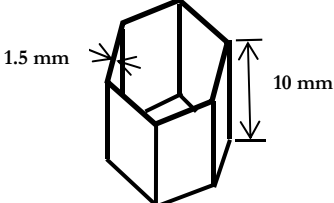
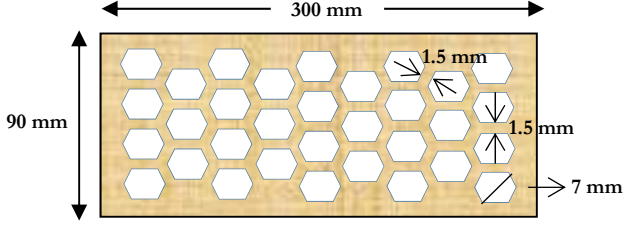
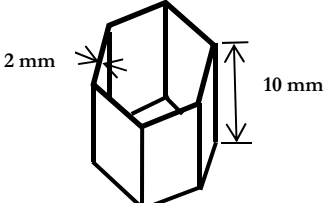
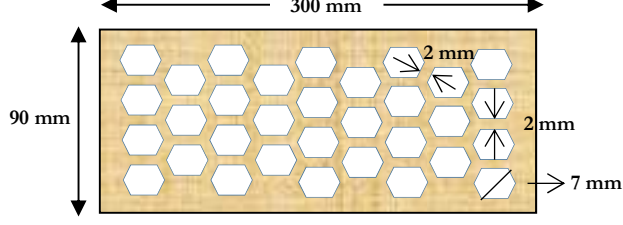
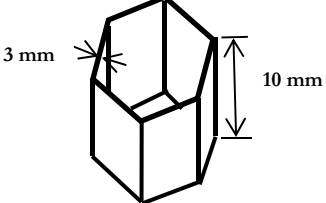
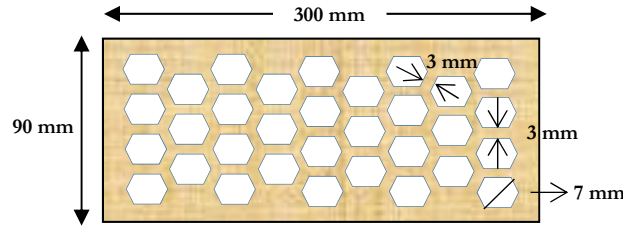
Rubber wood is regarded as a sustainable resource has been one of the strong driving forces in the wood industry in Malaysia. Besides on those mentioned, researchers are also aggressively carrying out studies on different components and form of rubber wood as green and renewable natural resources to work with polymers in the composite field for various purposes [37]–[42].

However, there is lack of study on the utilization of rubber wood with the honeycomb cellular design as the core in a sandwich structure. Therefore, in this research, the investigation on the design parameter of the rubber wood honeycomb cellular core will be carried out. It is because the design parameter is an important factor that to be taken into consideration prior fabrication that changes the mechanical properties of the structure. In this study, it focused to find out on the effect that cell wall thickness brought for bending and compressive tests.

2 Experimental Procedures

Rubber wood, as the honeycomb core was cut into the size of 300 mm x 100 mm plates with core thickness of 10 mm are milled into hexagonal shape using CNC gantry router MDX-540. The diameter of the honeycomb arrays for each of the parameter is adjusted to 7 mm each with different cell wall thicknesses which are 1 mm, 1.5 mm, 2 mm and 3 mm. In that way, each honeycomb cell is a distance away from one another according to the gap of the walls mentioned. The rubber wood that has been milled into honeycomb core is required to remove the debris on the surface with a sand grinder for consistent gripping between the interfaces. Table 1 shows the sample codes for the specimens with their wall thicknesses.

Tab. 1 The specimen with their respective cell wall thickness

| Sample Code | Wall Thickness of Hexagon | Illustration of Honeycomb Core |
|-------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| SWWS | |  |
| (7,1) |  |  |
| (7,1.5) |  |  |
| (7,2) |  |  |
| (7,3) |  |  |

For quick and easy removal of composites slab, a glass mould that applied with a layer of release coat on the inner surface was prepared. The facesheet used was required to be cut into the size of rubber wood honeycomb core. In order to facilitate the fabrication of the fiber-reinforced bio-honeycomb sandwich, a piece of rubber wood core is placed between a double layer glass fiber for the top and bottom facesheets. Epoxy and its hardener in the ratio of 1:1 were thoroughly mixed with gentle stirring to minimize air entrapment within the resin. Epoxy resin was applied via

conventional hand lay-up technique since it is suitable and widely applied in the large composite components.

Next, the natural sandwich composites consisting of two laminates of commercially available woven glass fibers as facesheet with a rubber wood honeycomb core were cured in the vacuum bag for at least 24 hours in the room temperature. This type of bag moulding is suitable for large composite component. A vacuum pump was connected to the ensemble containing the rubber wood composites throughout

the curing stage. This was carried out to ensure that the excess of resin and entrapped air were completely removed in order to produce quality composites. After curing, the samples were removed carefully of the glass mould for further experimentation procedures.

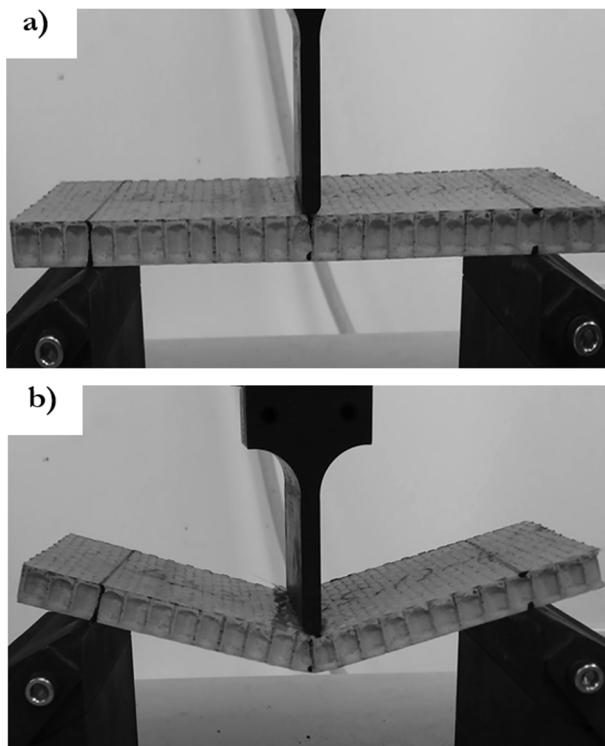


Fig 1 Flexural test according to ASTM C393 (a) beginning of test, (b) overall buckling at the end of test

The mechanical characterization of the honeycombs consists of flexural and compression tests

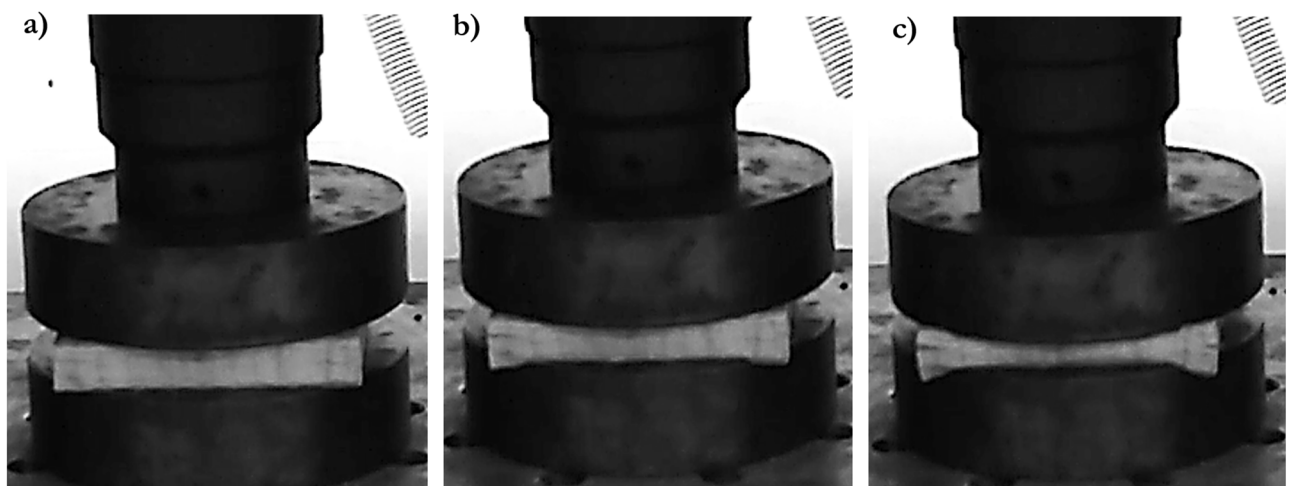


Fig 2 Flatwise compression test according to ASTM C365 (a) beginning of test - 0 load (b) middle of test - the specimen was slightly compressed and (c) end of test - the specimen was fully compressed

The compression strength of the specimen can be calculated from the formula as shown in Equation 2 where the F_{max} refers to the ultimate force prior to failure in the unit of N while A is the cross sectional area in mm^2 .

$$\text{Compressive strength} = \frac{F_{max}}{A} \quad (2)$$

In order to further understand the effect of cell wall thickness of rubber wood core on the sandwich

in order to find out the properties of sandwich made of rubber wood core. In flexural test, the specimens were prepared according to ASTM C393 using a Universal Testing Machine (UTM) as shown in Figure 1. At least five specimens in the dimension of 200 mm x 75 mm x 10 mm for each design were prepared to get its average performance. The test speed was adjusted to 2 mm/min and carried out within the room condition of $23 \pm 2^\circ\text{C}$. A consistent support span of 150 mm was set to support the specimens during bending. The failure behaviour of the specimens was observed.

The flexural strength is the maximum flexural stress sustained by the test specimen and could be calculated using the formula shown in equation (1) where P is load at a given point on the load-reflection curve (N), L is support span (mm), b is width of beam (mm) and d is depth of beam (mm).

$$\text{Flexural strength} = \frac{3PL}{2bd^2} \quad (1)$$

On the other hand, a minimum of five specimens for each design were prepared into square sized specimens of 75 mm x 75 mm each for the compression test according to ASTM C365. When the specimen is placed under UTM, the cross head speed is adjusted to 1 mm/min at the ambient temperature of $23 \pm 2^\circ\text{C}$. Figure 2 shows the specimen located at the centre of the loading block in order to ensure the entire surface of the composite receives even and consistent compressive force. The rubber wood sandwich composites with different cell wall thickness were tested to determine their compressive performance. Micrographs were taken to analyse the failure pattern of the rubber wood composites.

composite, Scanning electron microscopic (SEM) analysis was carried out using ZEISS EVO 50 at 15 kV EHT accelerating voltage. Before taking the micrographs, the specimens were sputter coated with gold over the surface uniformly to prevent electrical charging during the observation. Different magnifications were applied on the cross section of the specimens from different design parameters to observe and compare the failure occurrence that happened within the structures.

3 Results and Discussion

3.1 Flexural Properties

The three-point bending test was carried out to investigate the flexural behaviour of rubber wood honeycomb sandwich composite in accordance of ASTM C393. In the test, the integrity of the facesheet and honeycomb core would be known through the efficiency of the load transfer and facing stability.

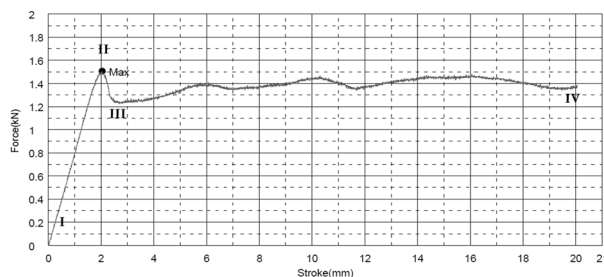


Fig 3 Force-stroke curve for rubber wood sandwich specimen (7,1)

Figure 3 shows a typical real-time force-stroke curve for the rubber wood sandwich specimen (7,1) under the flexural test. In the beginning of stage I, the specimen was efficiently receiving and transferring the

flexural load. It was able to resist more of the flexural load as the amount of the force applied was getting increasing. Under elastic deformation, the force shot up linearly until reaching the peak at stage II where the specimen was bearing the maximum force. The graph was almost linear which confirmed the Hooke's Law [43], [44]. It then experienced a sudden drop in terms of force indicating the force borne by the specimen had caused some of the fiber filament to break.

At the maximum applied load, the significant drop in load contributed to the compressive failure of the skin and subsequently followed by the shearing of the honeycomb core. The amount of force that the sample was able to resist reduced immediately to stage III. Debonding might be detected when top facesheet layer detached from the core on the left and right sections. Debonding could restrict a smoother load transferring phase between the facesheet and the core. In the case of fiber break, the specimen tried to achieve a stable condition to further resist the flexural force by distributing the load to a different part of the fibers where the bonding between the facesheet and honeycomb was still intact.

The force then fluctuated to reach to a plateau stage. At the plateau stage after the load had dropped from the peak, the flexural specimen was able to continue to sustain the load but could never exceeded the peak load. It is because only some part of the sandwich skin and the core were carrying the load after the irreversible failure that happened. As an advantage, the specimen was able to continue its role in the application even after failure rather than causing catastrophic failure to the entire sandwich structure. After a consistent plateau stage without much change, the load was removed from the specimen to leave it in the rest condition at stage IV.

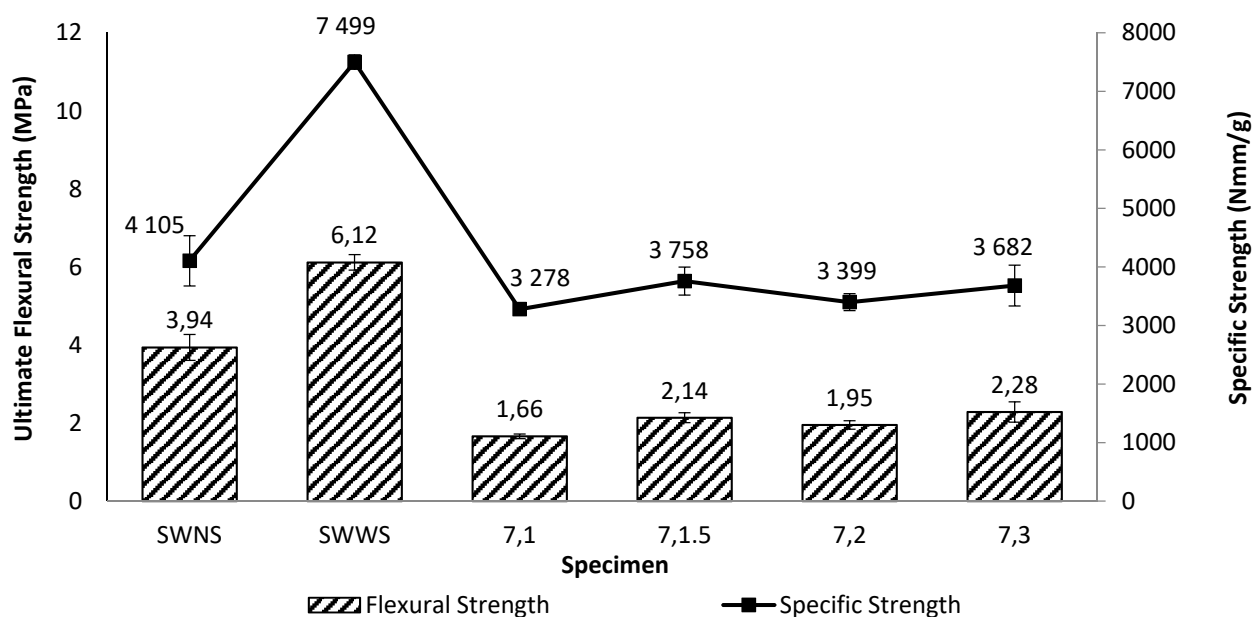


Fig 4 The ultimate flexural strength and specific strength for the different cell wall thickness variations

A graph representation as illustrated in Figure 4 featuring flexural strength and its specific strength. The solid wood core without and with skin, namely SWNS and SWWS respectively functioned as a benchmark to the other parameter variations. It is clear that specimen SWWS possessed good ultimate flexural strength and specific strength which was far beyond the rest of the specimens. In terms of ultimate flexural strength and specific strength, the specimen SWNS came up secondly after SWWS when compared to the rest of the honeycomb sandwich composites. From this trend, it could be stated that the solid wood core contributed greatly in the flexural performance than the honeycomb core. However, the density of honeycomb specimens was much lower than Specimen SWWS with the similar range of specific strength.

With facesheet in the sandwich structure definitely enhanced the flexural strength [45]. It is because the facesheet is directly playing a role in bearing load by distributing the load evenly throughout the area with lower stress. It minimized the phenomenon of sudden and catastrophic failure when the load only exerted on a particular spot. Meanwhile, the core was mainly involved in stabilizing, supporting and strengthening the entire composite [46]. On the other hand, it is reasonable that the flexural performance for SWNS and SWWS were excellent where the rubber core was made up of solid wood. The grain pattern in SWNS and SWWS were perfect and undisturbed. In a solid wood structure, the grain of the wood contributed greatly in resisting the bending load. The grain helped to put the wood together and not breaking apart. The grain size distribution even helped to stop the propagation of cracks when crack initiated at the weakest point [47]. In the honeycomb core, the grains were broken due to the fabrication of hexagonal cells. Hence, the discontinuous grains do not provide enough support to the wood structure as how it supposed to have exhibited in the solid wood.

When compare to the specific strength, it is noticed that the rest of the honeycomb core structures were closer to that of SWNS which ranges from 8.54 % to 20.15 %. In another word, the specific strength of the honeycomb composites was closer to that of solid wood core that was without glass fiber. It can be said that honeycomb sandwich has compatible optimal specific strength with the composite made up of solid wood core. It is advisable to use honeycomb core composite than solid wood composite for a load bearing panel where the density has become the concern. Furthermore, the range varied from 62.75 % to 72.88 % in terms of ultimate flexural strength and 49.89 % to 56.29 % in terms of specific strength when the lowest and the highest flexural performance of honeycomb specimens were compared to SWWS. From here, it shows that the specific strength which has a

smaller gap compared to ultimate flexural strength is the accurate property to be applied when density makes a significant difference in the composite components [48].

Moreover, when the wall thickness increased by 0.5 mm from 1 mm to 1.5 mm as seen in specimens (7,1) and (7,1.5), the ultimate flexural strength and specific strength increased by 28.92 % and 14.64 % respectively. Meanwhile, the ultimate flexural strength and specific strength improved 16.92 % and 8.33 % respectively for the wall increment of 1 mm from 2 mm to 3 mm. By increasing the wall thickness of the honeycomb cell, the performance was improved. It is because there was more contacting area between the cell wall and the fiber where the load could be transferred from the facesheet to the honeycomb cell more effectively [5], [45], [49]. Meanwhile, there was a slight decrease in the flexural performance when compared the Specimens (7,1.5) to (7,2). The wall thickness increased by 0.5 mm, the flexural properties was supposed to increase too according to the trend for the cell wall increment in the honeycomb core. However, the phenomenon could be due to the wall rupture during the fabrication itself as seen Figure 5. There was reduced contact area between the glass fiber facesheet and the wooden core for the transferring of flexural load.

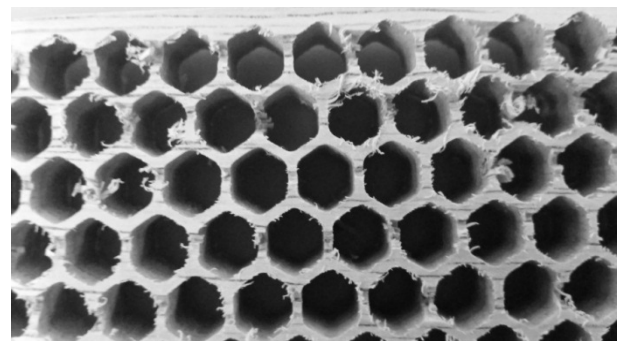


Fig 5 The rupture of cell wall in rubber wood honeycomb core

In three-point bending test, the composite panel that was placed on the support would experience compressive force on the upper part and tensile force on the bottom part which made it to deflect from the neutral line when the three-point flexural test as depicted in Figure 6 as claimed by Sharina [50] which is strongly agreed by Vitale [51]. Due to the compression and tension that going in the opposite direction, shear force was created at the centre section of the specimen [46]. Due to the nature of the bending test, the specimen experienced shear stress and various failures were noticed in the Figure 7. Since there was no skin to protect rubber wood core in SWNS, the side view of rolling shear and tension failure was observed in Figure 7(a). In order to present the actual failure in the specimen, the bottom view was capture

for better observation shown in Figure 7 (b). Catastrophic failure was possible to occur and could be dangerous if bending persisted. There was supportive finding that the facesheet was rather important to protect the core layer from further deformation [46].

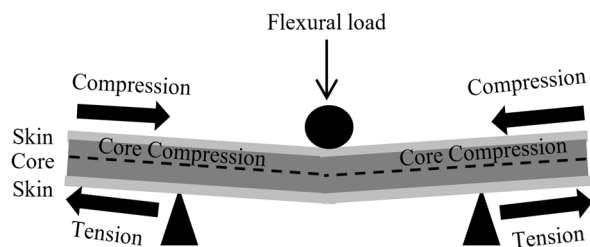


Fig 6 Three-point flexural test

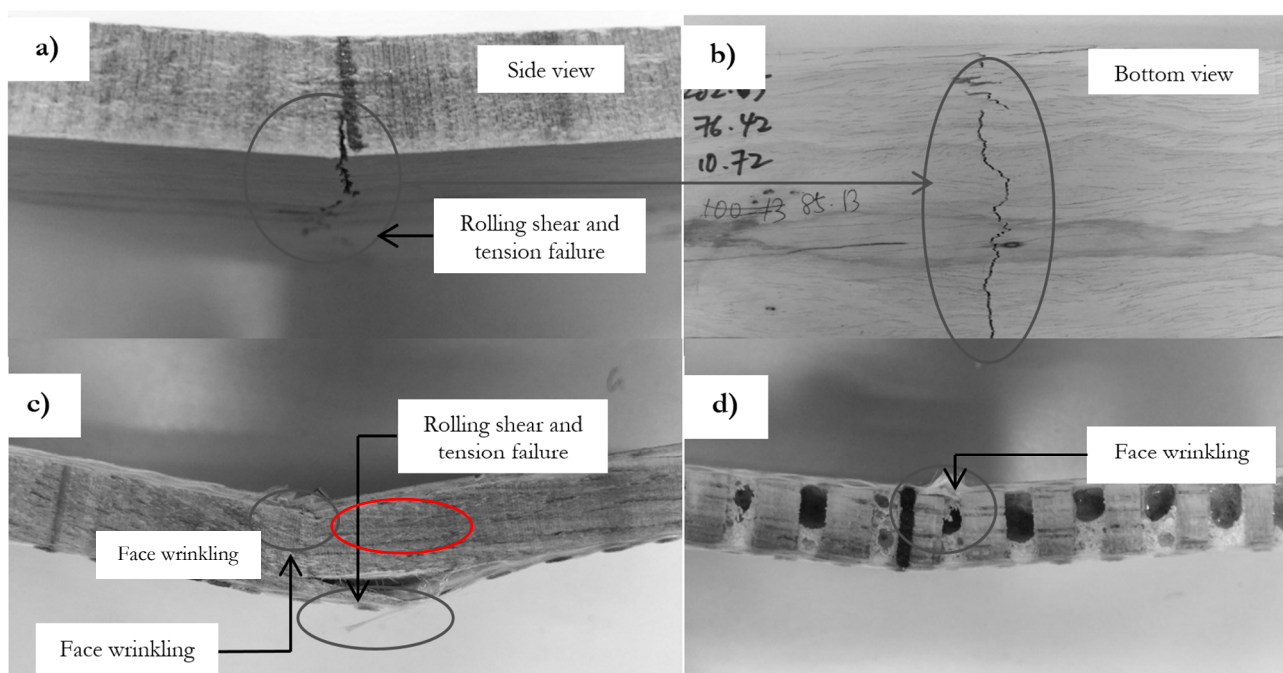


Fig 7 Failure condition after three-point bending test in (a) SWNS (side view), (b) SWNS (bottom view), (c) SWWS and (d) Specimen (7,3)

For honeycomb sandwich, the structures deflected more than the solid rubber wood. Therefore, they were able to bend more when under the flexural load at the same time supported by the facesheet. It could also be observed that the thick cell wall in Specimen (7,3) would not be over flexible with lower deflection yet able to sustain higher load than Specimen (7,1) which was thinner cell wall. With thicker cell wall, more bending force was passed efficiently to the bottom facesheet during the elastic deformation. It is because there was higher contact area with the increase of each cell wall. Cell walls and upper facesheet buckling was gradually noticed and finally ended with overall buckling and debonding between core and upper facesheet if bending test persisted with higher deflection.

On the other hand, surface fracture occurred on the rubber wood core and failed with crack sign directly under the load exertion point where the shearing force and bending moment reached the maximum at this location [52], [53]. For the core specimens with glass fiber facesheet such as Specimens SWWS and (7,3), the failure generated was not as major as SWNS. The rolling shear and tension failure happened at the bottom of the core. Refer to Figure 7(c), this type of the failure was often found in the core rather than the skin since the skin had higher stiffness and strength. The degree of failure of SWWS was not as severe as SWNS since there was facesheet in SWWS to distribute the load more evenly whereas the force exertion in SWNS underwent higher stress at a particular location.

Meanwhile, another common failure on the fiber reinforced composites was face wrinkling. It happened when the upper glass fiber facesheet developed buckling when experienced compression [51]. Majority of the specimens with facesheet developed face wrinkling, however, the degree of buckling depended on the deflection. The deflection in solid rubber wood core SWWS was smaller than that of those honeycomb sandwich composites such as Specimen (7,3). Consequently, the buckling was smaller and was not as severe as seen in Figure 4.4 (c). For honeycomb sandwich such as Specimen (7,3), the deflection was higher compared to SWWS. Thus, the wrinkling caused was bigger than that of SWWS. Overall, there was no face yield observed since the facesheet could sustain much higher load than the core [43].

3.2 Compressive Properties

The graph in Figure 8 can be categorized into two phases. It shows that there is elastic behaviour displayed by the rubber wood honeycomb composite at the beginning of during the out-of-plane compression. The force increased continuously in order to break the cell wall elastically in phase I. The glass fiber facesheet distributed the load evenly and was supported by the

cell wall. After a complete deformation of the elastic buckling of the core, the graph proceeded into phase II. It is seen the force slowed down tremendously, offering a much smaller gradient compared to that in phase I. The compressive force was continued to climb but in a lower rate as the load reached to the stiff material giving some resistance to the force exerted. At this stage, the cell wall buckled plastically and the fracture on the cell wall was permanent.

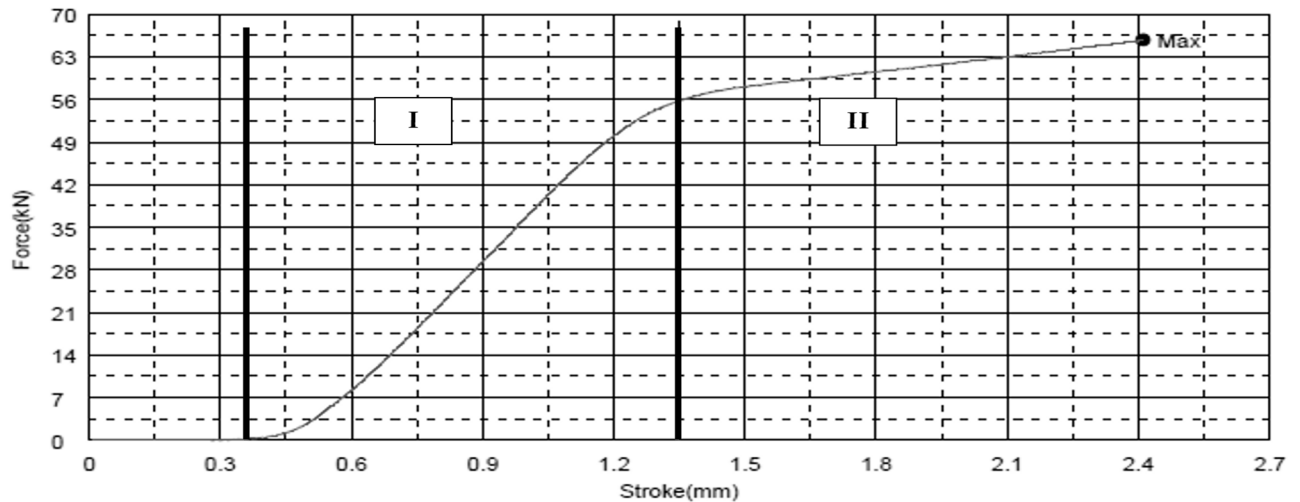


Fig 8 Force-stroke curve for rubber wood (7,3) specimen

The compressive strength of rubber wood increased as the wall thickness increased as displayed in Figure 9. The compressive strength of the Specimen SWWS is seen approximately 17 % higher than Specimen SWNS. This shows the importance of the function of the glass fiber in the Specimen SWWS composite structure to withstand the compressive load. As a high strength material, the glass fiber helped to distribute the load exerted equally from the skin to the rubber wood core and further transferred to the bottom facesheet to maximise the load bearing capacity of the sandwich structure. As the wall thickness of

the honeycomb cell increased starting from 1 mm, 1.5 mm, 2 mm to 3 mm, the compressive strength was getting higher to a total of 38 % from Specimen (7,1) to Specimen (7,3). The thicker the wall thickness, the contacting area between the skin and the rubber wood core was increased. Increase in wall thickness delayed the start of plastic deformation as more load could be carried along the elastic buckling of cell walls [54], [55]. With the thicker wall thickness and good interfacial bonding, the load exerted could be distributed more efficiently [45].

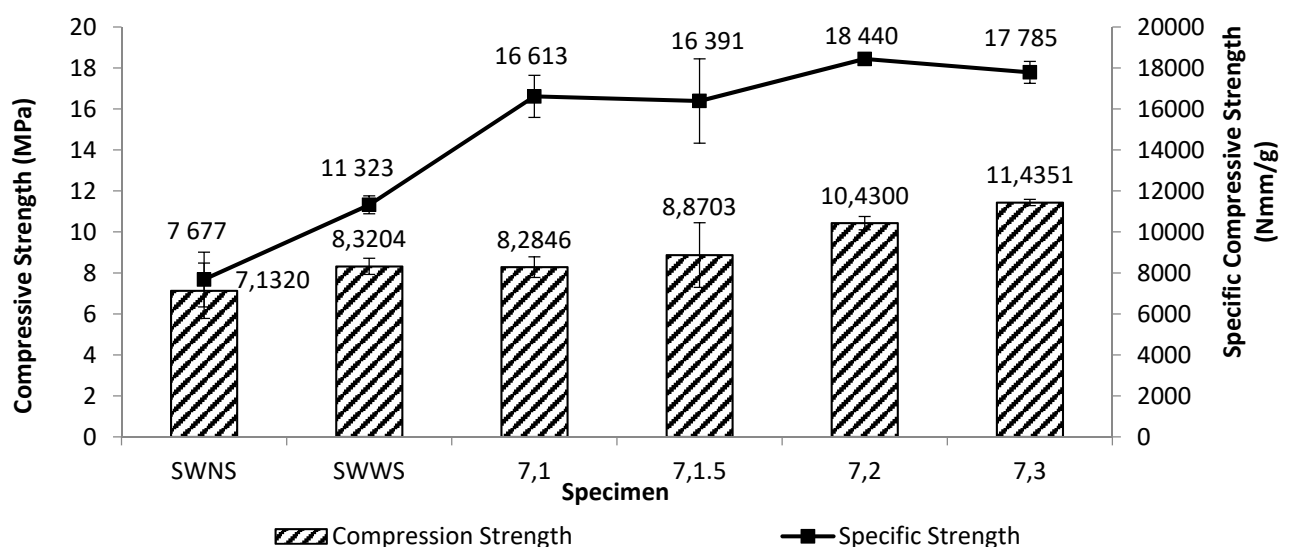


Fig 9 The compressive strength and specific compressive strength for cell wall parameters

In addition, the specific compressive strength was also in the increasing trend. The specific strength increased for the rubber wood core with higher cell wall thickness. By incorporating the honeycomb design as its core, the density of Specimen (7,1) is greatly reduced when compared to the solid rubber wood core in Specimen SWWS which pushing the rise of 47 % in the specific strength surprisingly. Next, there was only a small increment of 7 % in the compressive strength with the increment of 0.5 mm in the cell wall from Specimen (7,1) to (7,1.5). Due to the small positive change in the strength but larger increase in density, it caused a 1 % drop in the specific strength.

Besides, it is worth noting that the graph climbed again in specific strength for 12.5 % when the wall thickness increased from 1.5 mm to 2 mm. When the contacting area at the wall thickness increased, more compressive force could be distributed to the rubber wood honeycomb core and lastly to the bottom facesheet. Eventually, there is a 3 % drop at the specific strength of specimen (7,3) when compared with specimen (7,2). It is due to the compressive strength increased by only 9.64 % while the density increased by 11.61 % from specimens (7,2) to (7,3). It indicated that Specimen (7,2) at the optimum compressive performance. The properties may not show significant rise if the cell wall thickness is continued to increase. In turns, it only adds to the value of the overall density.

Rubber wood by nature is a strong wood. The distortion was not severe for all the specimens regardless the solid wood types or honeycomb core types. Diameter size of 7 mm was suitable as there was no dimpling. The compression properties for the honeycomb composites with thicker cell wall thickness overall were noticed to be better. With a larger contacting region between the facesheet and the core, the facesheet was able to transfer the compressive load borne by the facesheet more efficiently and smoother to the honeycomb core and lastly to the bottom facesheet. Figure 10 also revealed that how the core for Specimen (7,1) and Specimen (7,3) coped with the stress when the wall thickness was different. By having a smaller wall thickness of 1 mm for each of the cell in Figure 10 (a), there was distortion on the cell wall and was more noticeable when observed. Originally, the inclined cell walls were perpendicular to the facesheet forming 90° before the test. After compressed, the inclined cell walls experienced plastic deformation with the height reduced. The formerly straight inclined cell walls were seen bent and distorted [43].

Meanwhile, the inclined cell wall of 3 mm as pictured in Figure 10 (b) barely experienced distortion. The thicker cell walls helped to share the higher load and sustain it better with less distortion. There was a small

region by the corners that were not compressed due to the cylindrical loading block. As a result, the cell walls under the uncompressed region were seen bent outward with slips between grain layers were spotted. It was caused by the height difference before and after compressing. Somehow after the compression, the height was reduced slightly when measured due to the strong texture of rubber wood. On the region of compression, the inclined cell walls were vertically compressed with different degree of cell buckling and distortion depending on its thickness of the wall.

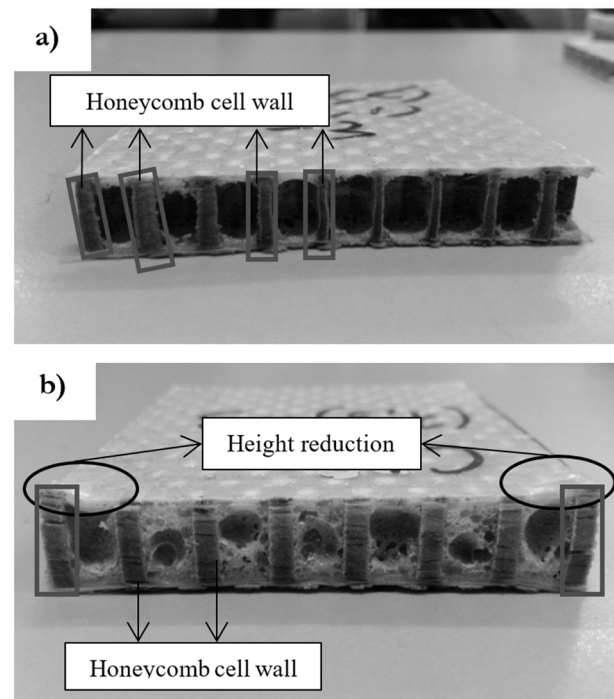


Fig 10 Out-of-plane compression test (a) Specimen (7,1) and (b) Specimen (7,3)

3.3 SEM Observations

From the SEM images, fillet formation could be observed clearly within the interface of facesheet and core. The adhesive fillet formed was a result of resin flow squeezed out during the pressure exerted upon curing. This portion of adhesive formed a transition zone between the foresheet and core. The ideal fillet should be symmetry with similar size on both side of the cell wall for better load transferring ability as shown in Figure 11 (a) [56]. With the fillet formation, it reduced the stress concentration at the overlap edge during compression. By providing larger area, the stress exerted was lower. Instead, asymmetrical fillet as in Figure 11 (b) could not transfer high amount of load with respect to time. As a result, the load-bearing ability was much lower. Moreover, the symmetrical fillet created a strong support to thicken the thin cell wall of the core.

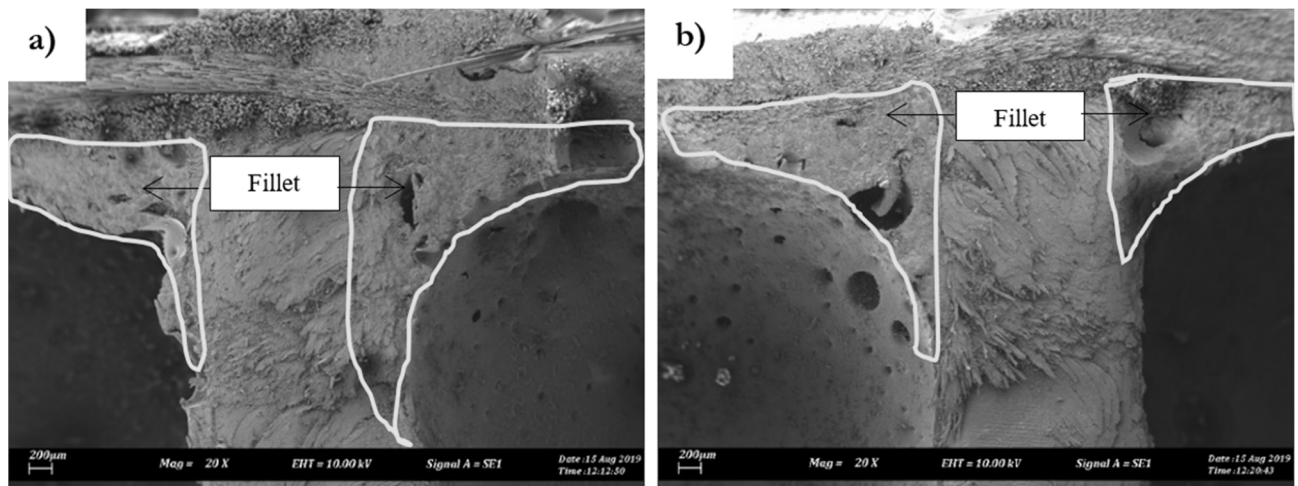


Fig 11 Different sizes of fillet formed (a) symmetrical and (b) asymmetrical

Besides, the size of the foam like fillet that depended on the amount of resin squeezed out during fabrication would directly affect the mechanical properties of the composites. It could be measured by the optical microscopy based on the triangular size of the fillet as in Figure 12 (a). The larger the size of fillet created bigger area for the smoother load transferring from the top facesheet to the bottom facesheet

through the honeycomb core [57]. Besides that, bubble formation was clearly seen on the fillet. Pores were unavoidable especially it was highly dependent on the technique and experience of one as well as the air trap within the hollow core. However, porosity in the adhesive fillet could pose a risk to the structure by decreasing the adhesion performance [58].

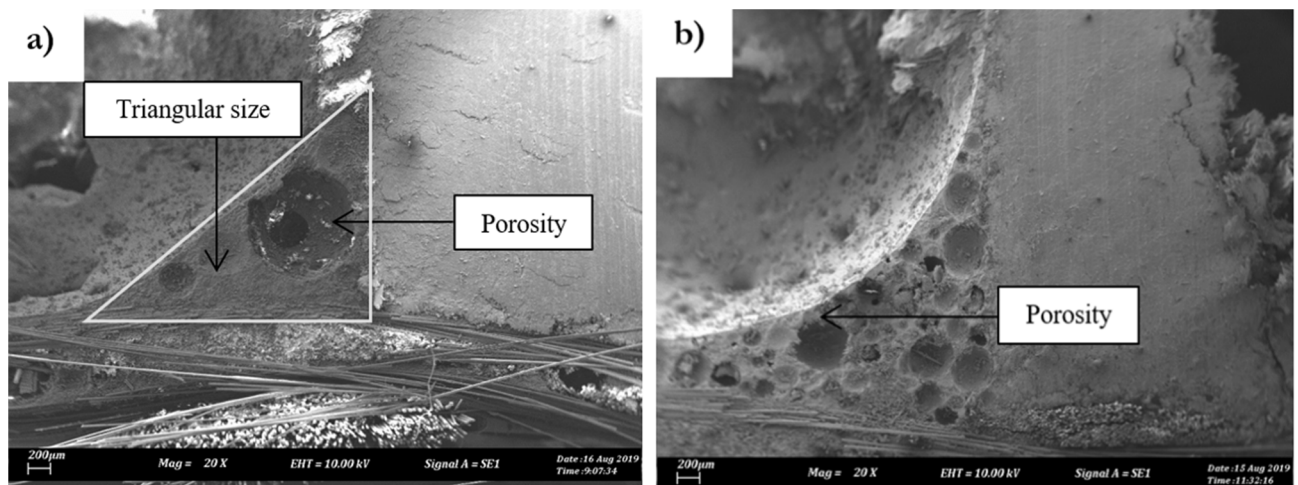


Fig 12 Fillet formation (a) size of fillet and (b) porosity

4 Conclusion

Research on sandwich composites utilizing rubber wood with honeycomb core design was carried out. The cell diameter used was 7 mm with different cell wall thicknesses to study the effect on the flexural and compression performance. Solid rubber wood is strong by nature to be used as a core material but it is advisable to be sandwiched with facesheet for improved flexural performance. The specific flexural strength of honeycomb sandwich with different wall thickness was in a close range with rubber wood solid core. Offering lower density and the core protected facesheets, catastrophic failure is not likely to happen

as in solid rubber wood core. With increasing cell wall thickness, the flexural properties are seen increased. Same goes to compression where the properties increase with the thickness of cell wall until a stage where increasing the cell wall does not make significant impact on the compression. The specific compressive strength decreases slightly when the density increases with the thicker cell wall.

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