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AN EXPERIMENTAL INVESTIGATION OF HONEYCOMB CORE FILLED WITH WOOD SAWDUST UNDER QUASI-STATIC LOADING

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ABSTRACT
In this paper the effects of honeycomb core filled with wood sawdust on their buckling mode and mechanical properties such as energy absorption are studied experimentally. Empty honeycomb core has limitation in energy absorption and filled it with other material can enhance the value of the energy. Wood sawdust is selected as the filler due to it is natural fiber and no chemical substance involve that can affect the health of the environment. Aluminium honeycomb core 3003 series and two types of wood sawdust, merbau and kenaf sawdust are subjected to quasi static axial compression loading. The results show the honeycomb filled with kenaf sawdust has higher energy absorption compared to empty honeycomb and honeycomb filled with merbau sawdust. But, for Specific Energy Absorb (SEA), the empty honeycomb core has higher value compared with the honeycomb with the filler due to the weight of empty honeycomb core is lower compared to other specimens.

Keywords: empty honeycomb core, merbau sawdust, kenaf sawdust.

INTRODUCTION
The metal honeycomb core has higher compressive strength and good in Specific Energy Absorb (SEA) compared with single thin wall structure. This is because the structure of honeycomb core has the number of cells that can sustain the amount of load and give the higher peak load compared to single thin wall structure. As prove, the honeycomb core structure is used in wide application especially for aerospace field due to this structure has high strength/weight ratio. In automotive industry, some improvement had been made especially for vehicle safety where the aluminium honeycomb core is used to combine with the aluminium column in car bumper system to increase energy absorb of the structure during initial collision. This is very importance to reduce the damage of engine cooling system and also to reduce the jerk to the driver during collision. This research had been continued by Zarei and Kroger (2008) and they found the circular metal tube is good to filled with aluminium honeycomb core in terms of SEA compared to square or rectangular metal tubes filled with aluminium honeycomb core.

Then, many researchers have studied the combination of metal honeycomb core with the other absorbing component. Due to honeycomb core structure has the hollow cell, the different method has been used where honeycomb core is filled with the other absorbing component. Aluminium honeycomb core filled with foam had been studied by Nia and Sadeghi (2010) under quasi-static loading. Experimentally, the authors found with the filled of foam the mean crushing strength and energy absorption increase up to 300% compared with empty honeycomb or foam. The densification point and wavelength of folds for honeycomb core filled with foam shows shorter compared to empty honeycomb. As the result, the number of fold is higher for the honeycomb filled with foam. Meanwhile, (Mahmoudabadi and Sadighi, 2011) had described foam filled in aluminium honeycomb has lower peak load to mean crushing load ratio compared to empty honeycomb in both quasi-static and low velocity impact loading. The lower ratio is very importance in dynamic loading especially to reduce the jerk of the structure during collision. The authors strain rate effect on foam-filled aluminium honeycomb had been investigated by Nia and Sadeghi (2013) and the authors found the number of folds is increased with the increment of strain rate.

Many researchers utilize the foam as the filled of honeycomb core. In this paper the filler is changed to natural fiber which is wood sawdust. The author, Singace (2000) has studied the capability of filled wood sawdust as the energy absorption device. The sawdust had capability to change the collapse mode of the PVC from multi-lobe to concentrina mode and therefore enhanced the energy absorbed of the structure.

This paper aims to describe the potential of local wood in Malaysia like Merbau and Kenaf in sawdust form to be a filler of aluminium honeycomb core for energy absorption. The collapsed mode of the structure will be observed especially with the influence of local wood sawdust.

PREPARATION OF SPECIMEN
In this experiment, Aluminium 3003 series is used as the material of honeycomb core. The cell size of honeycomb core is 0.01905 m and the foil thickness is 75 μm. The dimension of honeycomb core is 10 cm for width, length and height respectively. The honeycomb core is filled with two types of sawdust which are Merbau and Kenaf. Table-1 show the detail of specimens. As shown in Figure-1, the sandwich structure is applied where the top plate and bottom steel plate is bounded to

the honeycomb core using epoxy. The specimens are crushed using the Instron machine with the speed is setup 5 mm/minute as the condition of quasi-static loading.

Table-1. Detail specimens for cell size 0.01905 m.

Specimen label	Density of honeycomb core (kg/m^3)	Density of sawdust (kg/m^3)	Type of sawdust
A1	27.802	0	Empty Honeycomb
B1	27.789	224.08	Merbau
B2	27.806	240.14	Merbau
B3	27.806	256.24	Merbau
C1	27.789	203.47	Kenaf
C2	27.801	217.65	Kenaf
C3	27.794	238.20	Kenaf

Figure-1. Aluminium honeycomb core filled with (a) merbau sawdust, (b) sandwich structure

RESULT AND DISCUSSIONS

Figure-2 shows the deformation mode of honeycomb structure filled and non-filled with merbau and kenaf sawdust at 10 mm displacement. The buckling mode starts from the top level of honeycomb structure for all specimens. The progressive buckling is occurred from top to bottom level of honeycomb structure. The details description of buckling mode for empty honeycomb core has been described by Pokaad and Said (2014). But, at 40 mm displacement as shown in Figure-3, the honeycomb filled with merbau sawdust has the crack propagation in the outer surface of honeycomb core. The crack propagation is larger to observe with the increment of density merbau sawdust. The crack is smaller for honeycomb core filled with 224 kgm^{-3} merbau sawdust compared with 256 kgm^{-3} merbau sawdust. Honeycomb filled with kenaf sawdust also start to create the crack propagation but the crack is not large like the merbau sawdust. This is because the filled density of merbau sawdust is larger than kenaf sawdust

The number of fold becomes less as the density of wood sawdust increase. This is because the compressive load will make the filler more dense and rigid. This situations will generate the amount of pressure to the honeycomb core and the weak point of honeycomb core will start to crack. As shown in Figure-4, the weak point is along the pitch edge. The panel of pitch edge is bonded with epoxy and also the thickness of the panel just single thickness which is 75 μm. Compared to side edge where the panel is not bonded by epoxy and also double thickness, the pitch edge is easy to growth the crack propagation. This crack make the filler exposed out from honeycomb core. Meanwhile, for empty honeycomb the progressive buckling continues from the top plate to bottom plate and no crack is growth as shown in Figure-2(a). Meaning that, the filler is the main contribution of crack growth in honeycomb core. The filler also create less number of fold compared with empty honeycomb core.

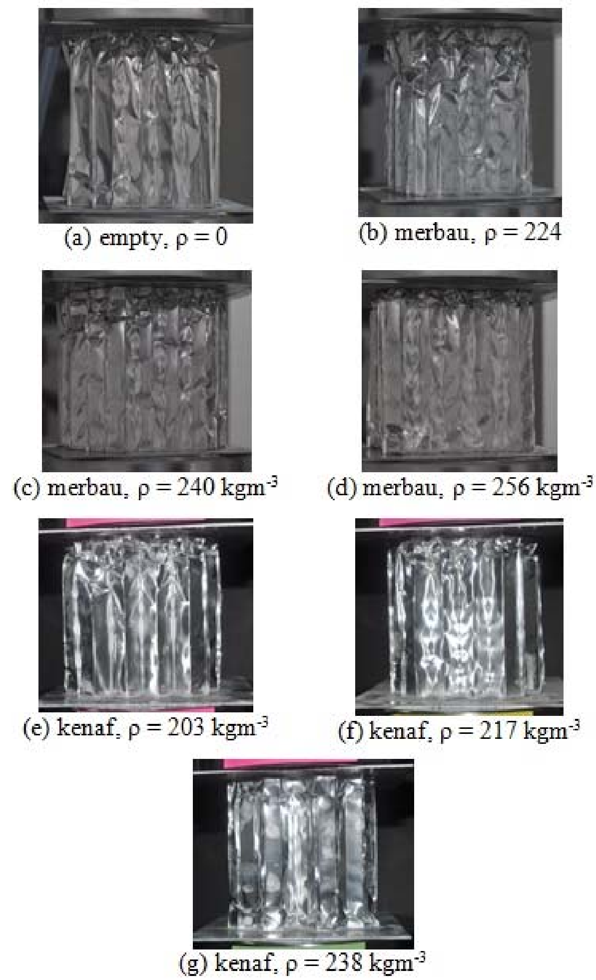

Figure-2. Mode of deformation of honeycomb with sawdust at displacement 10 mm for (a) empty honeycomb, ρ = 0, (b) filled merbau sawdust, ρ = 224 kgm^{-3}, (c) merbau sawdust, ρ = 240 kgm^{-3}, (d) merbau sawdust, ρ =256 kgm^{-3}, (e) filled kenaf sawdust, ρ =203 kgm^{-3}, (f) kenaf sawdust, ρ =217 kgm^{-3} and (g) kenaf sawdust, ρ =238 kgm^{-3}.

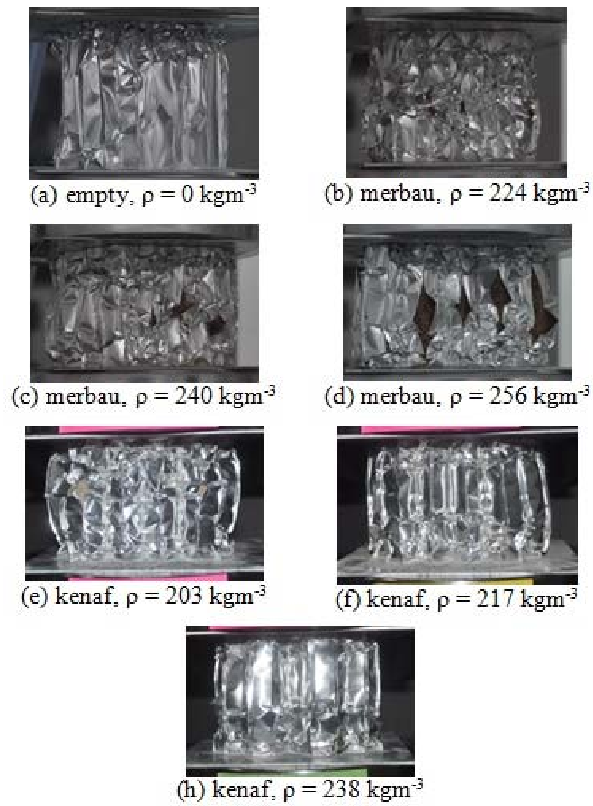

Figure-3. Mode of deformation of honeycomb with sawdust at displacement 40 mm for (a) empty honeycomb, ρ = 0, (b) filled merbau sawdust, ρ = 224 kgm^{-3}, (c) merbau sawdust, ρ = 240 kgm^{-3}, (d) merbau sawdust, ρ =256 kgm^{-3}, (e) filled kenaf sawdust, ρ =203 kgm^{-3}, (f) kenaf sawdust, ρ =217 kgm^{-3} and (g) kenaf sawdust, ρ =238 kgm^{-3}.

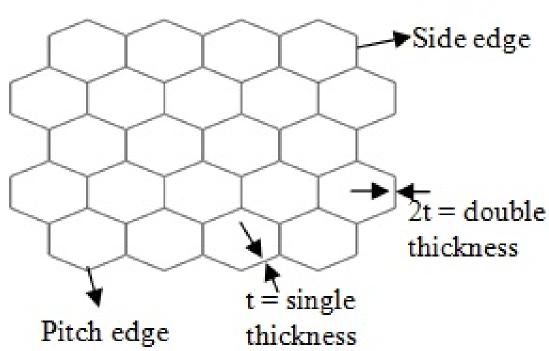

Figure-4. Configuration of honeycomb core structure.

Figure-5 shows the force vs displacement for empty honeycomb and filled with merbau sawdust. The initial peak of force is is represent the yield strength. There is not much different in terms of yield strength between empty honeycomb and filled with merbau sawdust. But, after the yield strength of empty honeycomb enter the plateau region where the pattern of the force is flat with the increment of displacement. Meanwhile, the honeycomb filled with merbau sawdust has higher force in this region compared to empty honeycomb. The force is increased by the increasing of sawdust density. Besides that, the force of filled sawdust is suddenly drop between 15 mm to 20 mm displacement. The force is drop due to the crack start to grow in honeycomb core. The densification strain, ε_d is decreased for the honeycomb filled with sawdust compared with empty honeycomb. It is found that, ε_d the filled of sawdust is at the displacement of 35 mm while the empty honeycomb core is at 85 mm. This pattern of graph is similar with filled kenaf sawdust in Figure-6.

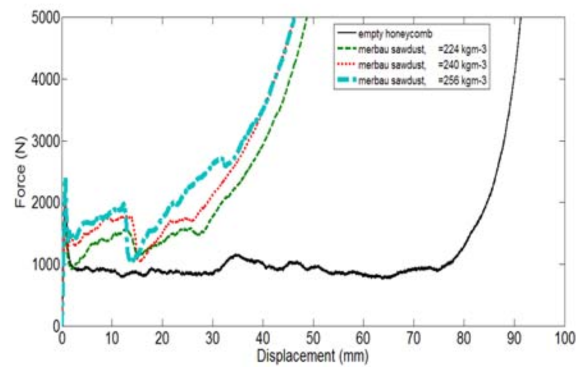

Figure-5. Graph force vs displacement of empty honeycomb core and filled with merbau sawdust.

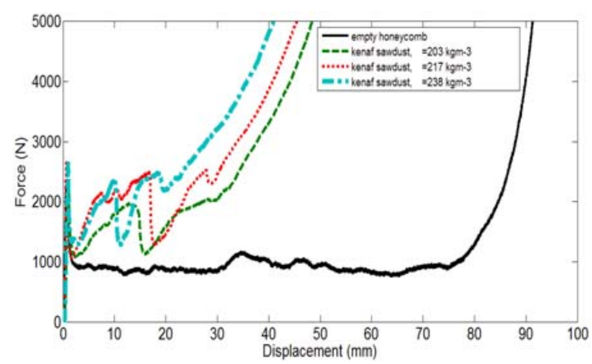

Figure-6. Graph force vs displacement of empty honeycomb core and filled with kenaf sawdust.

Figure-7 shows the comparison of the graph force-displacement between the honeycomb core filled with merbau sawdust and kenaf sawdust. Honeycomb core filled with kenaf sawdust has higher value of force compared with filled with merbau sawdust especially when filled density of kenaf sawdust, ρ = 238 kgm^{-3}. Based on the graph, the kenaf sawdust has the faster drop force against the displacement compared to fill with merbau sawdsut. Meaning that, the kenaf sawdust is easy to experience the crack propagation to honeycomb core compared to merbau sawdust. This is because the particle size of kenaf sawdust is smaller than the particle size of merbau sawdust as shown in Figure-8. The smaller of the particle, the less space for the particle to move especially

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to move in horizontal direction when it is filled in the honeycomb core.

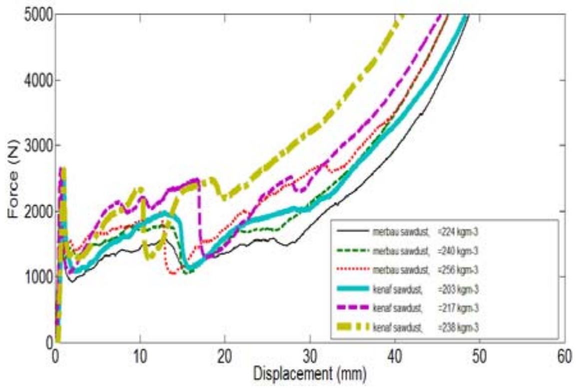

Figure-7. Graph force vs displacement of honeycomb core filled with merbau and kenaf sawdust respectively.

(a) merbau sawdust (b) kenaf sawdust

Figure-8. Photograph for sawdust.

Figure-9 shows the energy absorption of empty honeycomb, honeycomb filled with merbau sawdust and kenaf sawdust. Energy absorption is defined based on the area under the graph for force-displacement. From the graph, the density of the filler is the main criteria to change the energy absorb of the structure. The energy absorption can be increased if the density of the filler is increased.

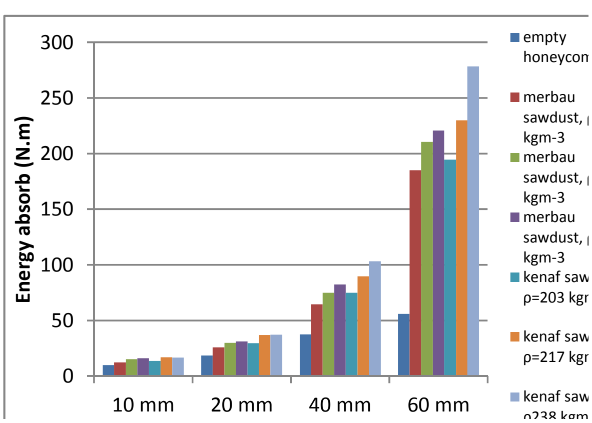

Figure-9. Energy absorption vs displacement for empty honeycomb core and filler with merbau and kenaf sawdust.

But, for the Specific Energy Absorb (SEA), the filler is not good to increase the SEA value as shown is Figure-10. This is because, SEA is depends on the weight of the structure and by filling the honeycomb core with the sawdust, the weight of the structure is increased.

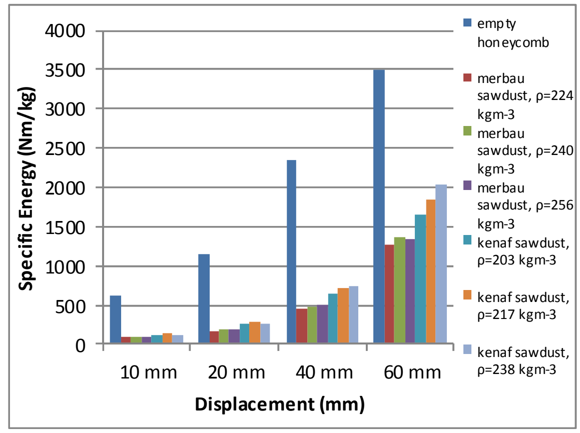

Figure-10. Specific Energy Absorb (SEA) vs displacement for empty honeycomb core and filler with merbau and kenaf sawdust.

CONCLUSIONS

In this paper, the effects of merbau and kenaf sawdust filling of Aluminium 3003 series honeycomb core on their deformation and mechanical properties such as energy absorption and SEA are studied experimentally. The important results are as follows:

- Natural fiber like wood sawdust has the potential to be the filler of honeycomb core. The experiment result shows the energy absorption of honeycomb core filled with wood sawdust is increased more than 300% compared with empty honeycomb core.
- Empty honeycomb core shows the progressive buckling mode from the top surface until the bottom surface of honeycomb core. Meanwhile, the honeycomb core filled with sawdust only experinced the progressive buckling on the initial stage of the crashing and then the crack propagation is occurred in the middle of honeycomb core.
- The denser filler material, the rate of crack propagation is higher.
- The pitch edge in honeycomb core is the weak point in honeycomb core and easy to produce crack or face panel debonding. This is because the pitch edge is made from a single thickness foil.
- Honeycomb filled with kenaf sawdust has higher energy absorption compared to honeycomb filled with merbau sawdust. The main contribution is kenaf sawdust has smaller particle size compared to merbau sawdust. The size of sawdust effects the energy absorption value of the structure.
- Empty honeycomb has higher SEA value compared to fill with sawdust. This is because, the filler will

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increase the weight of the structure and it will make the SEA become lower.

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