The Influence of Starch in Oil Palm Trunk Particleboard without Synthetic Adhesive

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Oil palm trunk particleboard without synthetic adhesive has been introduced as one of the potential green technology products as an alternative to the synthetic resin bonded particleboard. The chemical constituents of the lignocellulosic materials are important in allowing particles to achieve self bonding. The main objective of this study was to evaluate the influence of starch content on the physical and mechanical properties, as well as some biodegradation activities including termite decay and soil burial decay of the particleboard without synthetic adhesive. Internal bonding strength, modulus of rupture, thickness swelling, and soil burial were performed according to British Standard and European Standard. The termite decay on specimen was evaluated with *Microtermes gilvus*. Addition of starch into specimens resulted in adverse effect on thickness swelling but improved mechanical properties of the samples. However, removing starch containing in particles showed insignificant effect on mechanical properties of the specimens. Weight loss of specimens exposed to termites was not affected by starch content statistically. However, soil buried test samples had significant weight loss.

Keywords: Particleboard without synthetic adhesive, Oil palm trunk, Starch

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INTRODUCTION

Formaldehyde-based resins are commonly used as binder in particleboard manufacture. The formaldehyde-based resins that crosslink as they cure generally yield particleboard with excellent properties. However, concerns regarding health and environmental issues from the formaldehyde-based products are getting more and more important. Also, the increasing price of synthetic adhesives burdens the cost of overall particleboard production (Buyuksari *et al*. 2010). These issues have motivated the effort

to seek alternatives, and particleboard without synthetic adhesive is one of the potential approaches. Particleboard without synthetic adhesive is the lignocellulosic-based panel where the lignocellulosic materials are bonded together without using synthetic adhesives (Anglès *et al*. 2001). Processing parameters of making particleboard without synthetic adhesive, including appropriate hot pressing conditions and the type of lignocellulosic material, are able to trigger the reaction of the chemical constituents contained in the lignocellulosic itself, and together with the fibre crosslinking, to achieve the self bonding between particles (Hashim *et al*. 2011).

Starch has been proposed as being one of the potential chemical constituents in promoting lignocellulosic particles to achieve self bonding (Hashim *et al*. 2011). Starch is a carbohydrate polymer consisting of glucose units, which makes it similar to cellulose. However, one of the differences between cellulose and starch is that starch can dissolve in warm water to turn into paste form. Starch is commonly used as glue for household application, and it is also used as an adhesive in papermaking industries. Starch and its derivatives are also employed as raw materials in synthetic resins production (Onusseit, 1993). With such adhesion properties, starch could potentially act as a natural binder to promote the bonding between particles.

In a previous study, oil palm trunk showed great potential as a lignocellulosic material to produce particleboard without synthetic adhesive (Hashim *et al.* 2001). Particleboard without synthetic adhesive made from oil palm trunk also showed promising mechanical properties (Hashim *et al*. 2011). Some studies of the influence on oil palm trunk particleboard without synthetic adhesive including the parameter process and particles geometry have been carried out in the past (Hashim *et al*. 2010; Boon *et al*. 2013). The influence from the age of oil palm and the effect of adding sugar to the particleboard without synthetic adhesive was reported in Lamaming *et al.* (2014). However, there is still little information regarding the influence of starch on properties of particleboard without synthetic adhesive. According to some studies, the yield of starch in oil palm trunk is promising (Mohd Noor *et al.* 1999; H'ng *et al*. 2011). Thus, the objective of this study was to investigate the function of starch in particleboard without synthetic adhesive made from oil palm trunk. The influence of starch on the physical properties, mechanical properties and some biodegradation activities of the specimens were investigated. Native tapioca starch was used as adding starch to specimens to evaluate the influence of starch on specimens of starch level above origin starch containing in oil palm trunk.

EXPERIMENTAL

Particles Preparation

Oil palm trunk harvested from FELCRA Kampung Gajah Perak, Malaysia was chipped into coarse particles and ground with a grinder to the size that passes through a 2 mm sieve. Three different types of particles were produced. These three type particles were acid pretreated particles, starch add-on particles, and particles without further treatment/add-on. Acid pretreatment was introduced to remove the starch containing in the oil palm trunk particles. Acid pretreatment was performed with 0.8% sulphuric acid at

ratio of 1g process was followed by autoclave at 121 °C for 30 min and 60 min. Starch add-on particles were performed by using 3% and 5% (w/w, oven dried weight) food grade tapioca starch blended with oil palm trunk particles. All three type particles were air dried to approximately 10% moisture content.

Chemical Constituent

Untreated oil palm trunk particles and particles that had undergone acid pretreatment were ground and sieved with 40 mesh size. Sample preparation was performed according to TAPPI T 264 cm-97 (1997). Extractives composition was conducted according to TAPPI T 204 cm-97 (1997). Holocellulose composition was carried out based on method of Wise *et al.* (1946). Cellulose composition was determined by dissolving hemicelluloses with 17.5% sodium hydroxide. Hemicelluloses composition was also determined by weight reduction of cellulose composition from holocellulose. Additionally lignin composition was measured according to TAPPI T 222 om-02 (2002).

Starch was extracted, and the yield was determined according to method conducted by H'ng *et al.* (2011). Oil palm particles were soaked in 0.2% sodium metabisulfite solution at room temperature for 72 h. The slurry was filtered and the residue was washed with distilled water. The residue was then centrifuged to separate starch–protein mixture. The starch content of the sediment was measured using UV spectrophotometer at wavelength 650 nm.

Starch Characterization

Carbon, hydrogen, sulphur, and nitrogen contents of the starch were determined using Perkin Elmer 2400 Series II CHN elemental Analyzer. The percentage of oxygen containing in starch was estimated by subtracting amount of carbon, hydrogen, sulphur and nitrogen from 100% (Mansouri *et al*. 2006). The ash content of tapioca starch was also determined gravimetrically with approximately 1 g starch sample calcined in a furnace at the temperature of 575 °C for 3h (Mansouri *et al*. 2006).

The differential scanning analyses was carried out in nitrogenous atmosphere from 50 °C to 200 °C at the heating rate of 10 °C/min. The thermal gravimetric analysis was also performed in nitrogenous atmosphere from 50 °C to 800 °C at the heating rate of 20 °C/min.

Particleboard without Synthetic Adhesive Manufacture

The untreated particles, particles that had undergone acid pretreatment, and particles with starch add-on were used to form mats with targeted density of 0.60 g cm^{-3} at a thickness of 0.5 cm, by hot pressing using a temperature of 200 °C for 20 min at a pressure of 10 MPa, respectively (Boon *et al*. 2013). Each type of particles produced particleboard without synthetic adhesive in triplicates. Particleboards without synthetic adhesive were conditioned at 20 $\pm$ 2 °C and 65 $\pm$ 5% relative humidity before proceeding with further evaluation. Thickness swelling was determined in accordance with EN 317 (1993). Internal bond strength and modulus of rupture were conducted according to EN 319 (1993) and EN 310 (1993) respectively.

Termite Deterioration of the Samples

The termite test was performed according to ASTM D3354-74 (1999). Fine sea sand was washed and sieved with 0.42 mm mesh and oven dried. The dried sand was mixed with drinking water at a ratio of 3 parts of sand to 1 part of water by weight, and distributed evenly in a 30 cm x 25cm x 20 cm polyethylene container with good air circulation. The specimens with size of 2 cm x 1 cm x 0.5 cm at triplicates were oven dried and weighed and randomly placed into a testing arena with label. The *Macrotermes gilvus* were collected from infested wood at in Kedah, Malaysia. Termites were sorted into the test arena, with a total of 1000 workers and 50 soldiers. The test arena was left in a place that was protected from light for 30 days. After 30 days, specimens were collected, cleaned, and oven dried, and the weight loss of each samples was determined.

Soil Burial Test of the Samples

The soil burial test was conducted according to BS 1982-2 (1990) with modifications. Samples of dimension of 10 cm x 1 cm x 0.5 cm were oven dried, and their weight were recorded. The soil burial test was carried in laboratory. Soil was filled into 60 cm x 30 cm x 45 cm aquarium with 50 % volume occupied. The specimens were labeled and randomly buried with 8 cm deep into test arena for 8 weeks. The samples were then collected, carefully cleaned, oven dried and weighed, to determine their weight loss.

Scanning Electron Microscopy

The particleboard without synthetic adhesive specimen was cut into about 0.5 cm by 0.5 cm cross sections. All samples were gold sputtered using sputter coater model Polaron SC 515 $\pm$20 nm. The specimens micrograph image were taken with LEO Supra 50 Vp field emission scanning electron microscope (FESEM)

Statistical Analysis

The results were performed with statistical test, all result were expressed as mean $\pm$ SD. The comparison of mean was evaluated with Tukey HSD.

RESULTS AND DISCUSSION

Chemical Constituents of Oil Palm Trunk Particles

Table 1 displays the chemical constituents of untreated and acid pretreated oil palm trunk particles.

Table 1. Chemical Composition of Oil Palm Trunk Samples with and without Acid Pretreatment

	Extractives (%)	Alphacellulose (%)	Hemicelluloses (%)	Lignin (%)	Starch (%)
Blank	14.51	41.55	22.11	18.87	11.56
30 min	11.03	51.39	18.12	17.43	9.63
60 min	10.4	54.59	15.64	15.31	3.7

Based on the findings, the increase of the treatment duration decreased the amount of starch compounds. The amount of starch was reduced to 3.7% after 60 min of acid pretreatment. The attempts of producing oil palm particles with acid pretreatment beyond 60 min was carried out in preliminary work, and it resulted in severe degradation of the lignocellulosic material. As illustrated in Fig. 1, the blank specimens had large amounts of starch granule inside the pit.

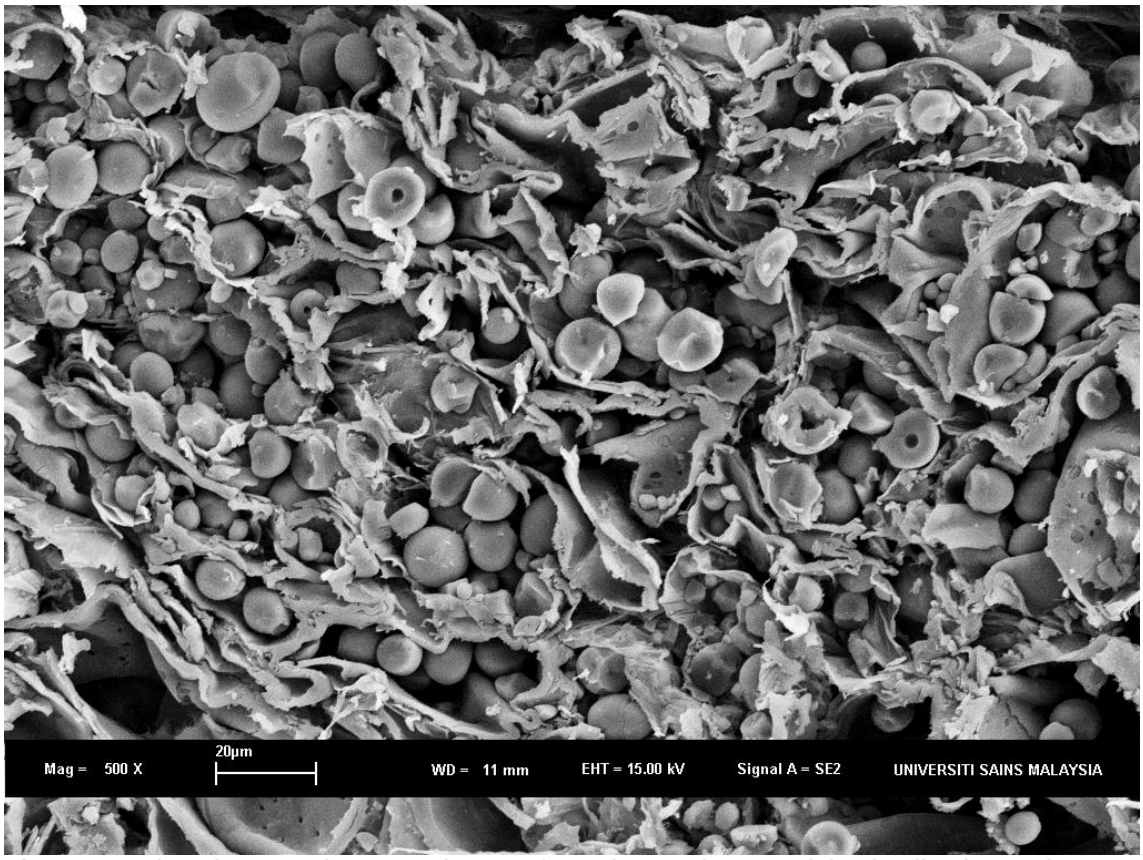

Fig 1. Scanning electron microscopy image of starch granules containing in oil palm trunk.

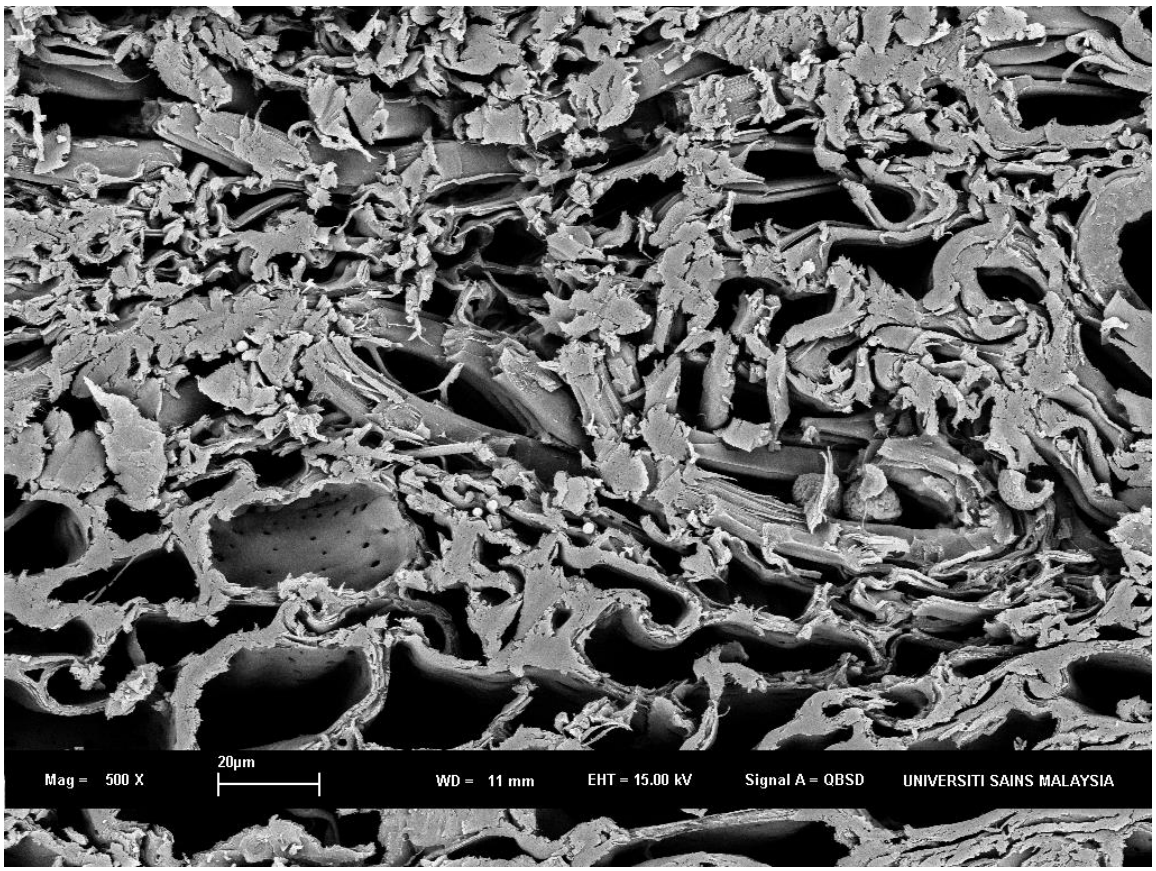

Fig 2. Scanning electron microscopy image of specimens made with particles undergone 60 min acid pretreatment.

On the other hand, specimens formed with particles that had undergone 60 min acid pretreatment, did not have starch granules inside the pit as much as blank specimens, as shown in Fig 2.

Starch Characterization

In this study, native tapioca starch was introduced to add onto the particles, as the tapioca starch has high similarity with starch found in oil palm trunk in term of shape and size (Fig. 1). This in agreement with the finding from Swinkels and Veendam (1985), compared with the starch found in scanning electron microscopy image (Fig. 1) of oil palm trunk. Furthermore, Noor *et al.* (1999) reported the amylose content of oil palm trunk starch is 19.5%. It is relatively similar with amylose content of tapioca starch reported by Swinkels and Veendam, which is 17%. However, starch extracts from oil palm trunk is not preferable, as was described by Mohd Noor *et al.* (1999) works. Based on his team finding, the starch extracted from oil palm starch using sodium metabisulfite solution in laboratory scales had lower purity. The extracted materials contained high ash content, and high protein content. Therefore, authors proposed native tapioca starch as adding starch to study the influence of starch of specimens with starch content higher than origin starch containing in oil palm trunk.

From the CHN/SO analysis, the native starch used in this study containing 39.82% of carbon, 6.82% of hydrogen, 0.18% of nitrogen, and no sulphur element was detected, and the oxygen amount was estimating at 53.18%. The nitrogen element detected in the samples could be due to protein content or nitrogenated compounds. Ash content of the tapioca starch was 0.21%. This finding suggests that tapioca starch has only little impurity of protein content and ash content. Therefore, native tapioca starch that showed good purity was selected.

The thermal behavior of food grade tapioca starch was determined. The curve of DSC is shown in Fig. 3. Based on the DSC finding, the peak of melting was fall at around 90 °C while the onset temperature was around 50 °C.

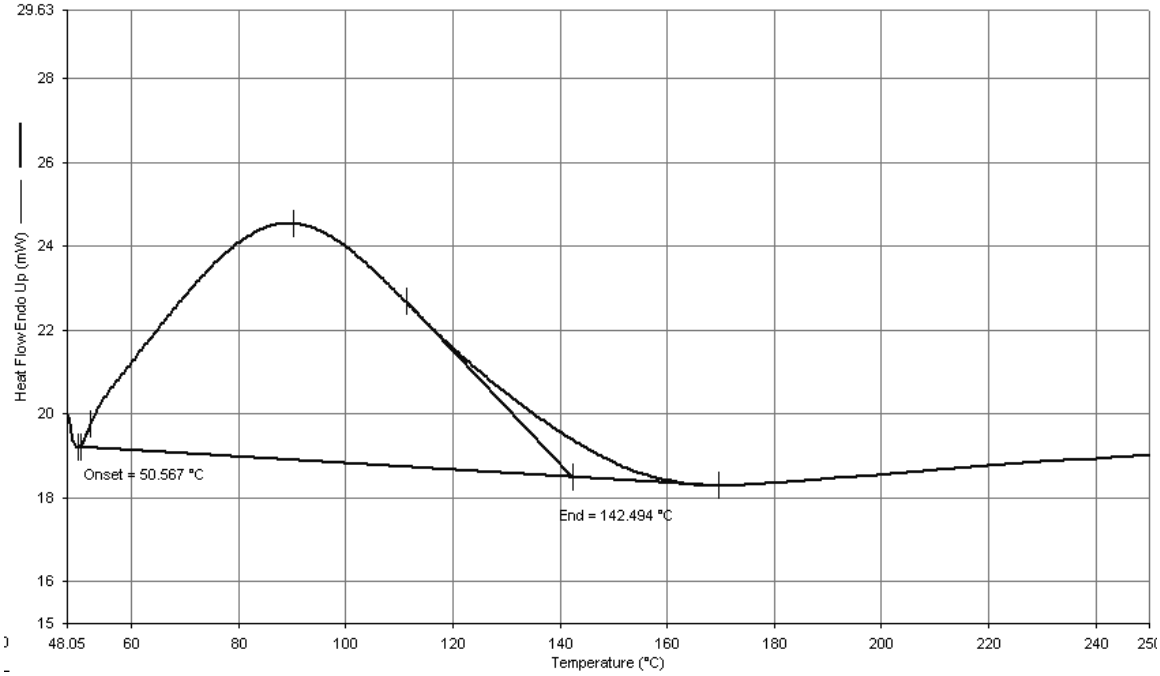

Fig 3. Differential scanning calorimetry analysis of tapioca starch.

As can be seen in the TGA curve (Fig. 4), the decomposition rate was at around 340 °C. Therefore, based on the thermal behavior of the tapioca starch, hot pressing temperature at 200 °C was suitable for the starch to react without thermal decomposition.

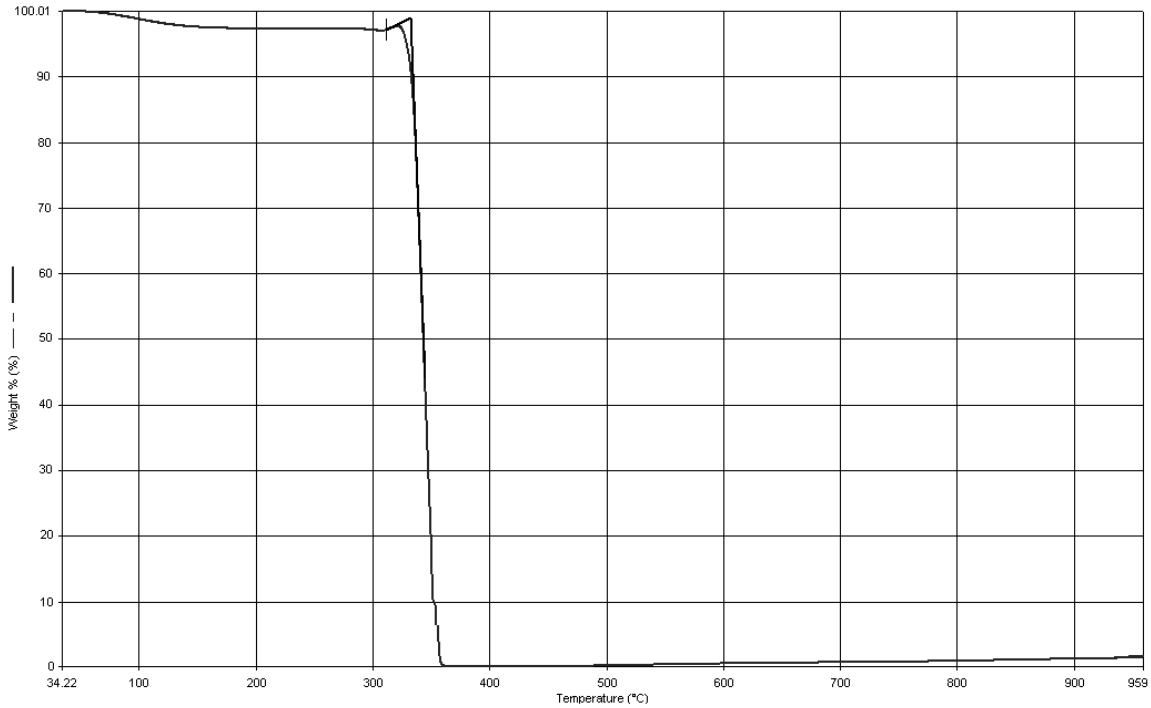

Fig 4. Thermo gravimetric analysis of tapioca starch.

Thickness Swelling of Samples

The thickness swelling of the panels is displayed in Table 2. An increase in addition of starch increased the thickness swelling of specimens. Meanwhile, the increment of acid pretreatment duration reduced the thickness swelling rate.

Table 2. Thickness Swelling, Internal Bond Strength and Modulus Rupture of Panel Specimens

Specimens	Thickness swelling (%)	Internal bond strength (N/mm^2)	Modulus of rupture (MPa)
Blank	26.00 ± 0.66a	0.66 ± 0.01a	15.41 ± 0.23a
3% starch add-on	28.81 ± 1.13b	0.72 ± 0.01b	16.97 ± 0.22b
5% starch add-on	31.59 ± 1.42c	0.76 ± 0.01c	18.35 ± 0.22c
30 min acid pretreatment	22.82 ± 0.66d	0.67 ± 0.01a	15.14 ± 0.38a
60 min acid pretreatment	19.28 ± 0.89e	0.68 ± 0.01a	15.38 ± 0.46a
*Different letter within the same column are statistical significant difference at α = 0.05.			

As mentioned previously, acid pretreatment was successfully removing most of the starch containing in the oil palm trunk particles. It is a fact that starch is hydrophilic influencing properties described above (Amini *et al*. 2013). The starch content influenced the water uptake of specimens. The high temperature during hot pressing seems did not change the hydrophilic behavior of starch. The add-on of starch into specimens caused the specimens to uptake more water after being immersed into water in the thickness swelling evaluation. The penetration of water into specimens caused the release of compressive stress between particles, hence increasing the swelling rate. However, the

reduction of water uptake of the acid pretreated specimens was not only due to starch. During acid pretreatment, the hydrophilic components such as hemicelluloses were also being hydrolysed (Anglès *et al*. 2001). This could contribute to the improvement on the stability against moisture/water uptake as well.

Mechanical Properties of the Samples

Mechanical properties of specimens, namely internal bond strength and modulus of rupture, are shown in Table 2. The increment on starch add-on amount significantly improved overall mechanical properties of the samples, Addition of starch filling the void between particles was able to improve the quality of contacts between particles. Furthermore, there is the possible of transition of starch into paste form when the starch encountering with steam moisture released from particles during hot pressing process. The resulting starch in paste form may help in improve the bonding of particles as well.

However, the mechanical properties of specimens with acid pretreatment had satisfactory strength characteristics. The mechanical properties of specimens made with acid pretreated particles showed insignificant different with specimens made with particles that had not undergone any treatment or add-on. It seems that removing the starch that originally was contained in the particles will not significantly affect the self-bonding of particles. One possible reason to explain this condition is that the starch originally contained in the particles, did not redeposit from pith and parenchyma to the surface of particles; hence the starch was not able act as a bridge to improve the bonding between particles. Thus, the starch originally contained in the particles was not able to function as binding agent to match the effect of the add-on starch. Therefore, starch contained in the particles did not significantly contribute to the bonding between particles of the particleboard without synthetic adhesive specimens.

Termite Decay and Soil Burial Test of the Samples

The weight loss of specimens after being exposed to termites for 30 days is shown in Table 3.

Table 3. Weight Loss of Panel Specimens after Exposed to *Macrotermes Gilvus* for 30 days

Specimens	Weight loss (%)
Blank	73.7 ± 2.1a
3% starch add-on	77.0 ± 13.2a
5% starch add-on	76.9 ± 6.6a
30 min acid pretreatment	74.4 ± 6.2a
60 min acid pretreatment	71.0 ± 4.6a
*Different letter within the same column are statistical significant difference at α = 0.05.	

The results showed no significant different of weight loss among the specimens. The average of weight loss of all these specimens was in the range of 71% to 77%. Also, the weight loss of all specimens had big variation. In this evaluation, the change of starch amount in the specimens was not influenced by the determination of termites in choosing target (specimens). The termites in the test arena invaded all these specimens randomly.

The weight loss of specimens after being exposed to soil burial decay for 8 weeks is shown in Table 4. Unlike termite decay, the weight loss of some specimens after being exposed to soil burial showed significant difference. From the result, comparing to blank, increasing the starch add-on amount increased the weight loss of the specimens. Meanwhile, increasing the acid pretreatment duration resulted in decreased weight loss of the specimens.

Table 4. Weight Loss of Panel Specimens after Being Exposed to Soil Burial for 8 Weeks

Specimens	Weight loss (%)
Blank	14.1 ± 0.3ab
3% starch add-on	15.1 ± 0.2b
5% starch add-on	16.8 ± 0.2c
30 min acid pretreatment	13.5 ± 0.2a
60 min acid pretreatment	12.9 ± 0.8d
*Different letter within the same column are statistical significant difference at α = 0.05.	

The soil burial decay test had a similar trend with the thickness swelling rate of the specimens. According to thickness swelling evaluation as presented previously, specimens made with particles that had undergone 60 min acid pretreatment showed the least thickness swelling rate. These specimens also resulted in the least weight loss after being exposed to soil burial test. Meanwhile, specimens made with 5% starch add-on showed the highest thickness swelling, and weight loss in soil burial decay.

It seems that weight loss in the soil burial decay was affected by water uptake ability of specimens. The staked specimens absorbed the moisture contained in the soil, and this made the specimens weak resistant against water uptake. The specimens became swollen due to the release of compressive stress, and the bonding of particles became loosened and exposing larger surface area. The bio-organisms containing in the soil were able to more easily penetrate into the loosened particles. This enlarged surface area accelerated the decay process.

Besides that water uptake ability that was influenced by starch content, the weight loss of specimens after being exposed to soil burial may also be caused by the nutrients from starch. It seems that there could also be the possibility the bio-organisms containing in the soil, especially microorganisms, were utilized preferentially by the specimens with higher starch content as starch as a source of nutrient (Borghei *et al*. 2010). With the nutrient supplies, the microorganisms that penetrated into specimens with higher starch content were able to grow faster and more sustainably in the specimens. In such, increased the weight loss of soil burial decay.

CONCLUSIONS

Starch significantly influenced the properties of oil palm trunk particleboard without synthetic adhesive. The behavior of each properties of specimen influenced by starch was different.

1. Starch adversely affected water uptake of specimens, causing greater absorption. Starch is hydrophilic.

2. Starch originally contained in the oil palm trunk showed insignificant effect on the mechanical properties of specimens; however, adding tapioca starch during the preparation resulted in an increase in mechanical properties. These results suggest that starch can be proposed as additives to enhance mechanical properties of particleboard without synthetic adhesive.
3. Starch did not influence the choices of termites. However, the starch content in panels affected the soil burial decay rate of specimens by way of reducing specimens resistance to water uptake. Also, starch could be the place where microorganisms are present.

ACKNOWLEDGMENTS

We would like to acknowledge University Postgraduate Research Scholarship Scheme awarded to Mr. Jia Geng Boon and ERGS grant (203/PTEKIND/6730054).

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Article submitted: September 10, 2014; Peer review completed: October 7, 2014; Revised version received and accepted: November 27, 2014; Published: December 14, 2014.