showed the highest weight loss compared to pure PVOH. This finding was associated with higher corn starch content in the packaging film. The PVOH, which is biodegradable due to its high hydrolysability, exhibited a higher resistance to soil burial degradation [9]. Boron / boric acid as reported in the various study was successfully accommodated as antibacterial and antifungal agents when they are mixed with polymers such as starch and PVOH [10]. The significant weight loss was reported in enzymatic degradation test on thermoplastic starch (TPS) when it is added with nano-SiO_2 content up to 6 % wt [11]. Therefore the main objective of this study was to investigate the decay resistance of particleboard bonded with starch/PVOH/SiO_2. Approximately 70 % of starch ratio with 30 % of PVOH and 3 % of Nano silicon dioxide (SiO_2) will be compared with their native starch and commercial binder.

MATERIAL AND METHODS

Oil palm starch extraction process

The oil palm starch extraction process followed procedure from previous studies [12,13] with a slight modification and has been described in details in the previous publication [14].

Oil palm starch modification process

In this study, the oil palm starch was modified with polyvinyl alcohol (PVOH) and crosslinked with 2 % of boric acid. The modification method was carried out based on previous studies [15,16] with a slight modification in term of amount of chemical and additives used in the modification process. Polyvinyl alcohol (PVOH) with molar mass = 99.000 g/mol (Sigma-Aldrich), glycerol (20 %) and Tween 80 (1 %) were used in this study. Boric acid with purity 98 % with a melting point at 171 °C and Tween 80 were purchased from Sigma-Aldrich. The starch ratio used in this modification process approximately 70 % mixed together with 30 % of PVOH was prepared.

All the mixtures used in this modification activity were weighed based on 15 % of the adhesive formulation. Firstly the 30 % PVOH was weighed and added with distilled water until it is marked up to 400 ml and placed in a 1000 ml beaker before being heated at 90 °C for 1 h. Then, the mixtures underwent constant stirring until all the PVOH crystals were completely dissolved. Next, the 70 % of oil palm starch samples and 20 % wt. of glycerol was added to the mixture and stirred for 1 h until dissolved. After that, 2 % of boric acid and 1 % of tween 80 were mixed together with starch and glycerol and stirred again for another 1 hr. The physical blending of 3 % of Nano silicon dioxide (SiO_2) was done into the mixture in the last phase of 3 h of overall modification process. Finally, all the mixtures were then poured into a container and oven-dried at 60 °C before being used as a binder for particleboard manufacturing.

Particleboard manufacturing

The particleboard was made from 70 % *Acacia mangium* and 30 % mixed hardwoods supplied by a local particleboard company in Negeri Sembilan, Malaysia. The density of particleboard was produced at 0.80 g/cm3 and the dimension for each board is 20.1 X 20.1 X 0.5 cm. The moisture content of particles was 8 %. Oil palm starch was extracted from oil palm trunk as described previously in other research work [12, 13]. About 15 % of starch based adhesive made from native oil palm starch and modified oil palm starch were prepared in this formulation and were weighed based on dry weight (w/w). A commercial binder, urea formaldehyde (UF) was used and using similar resin level. The starch based adhesive was prepared by mixing the starch powder with 150 ml of hot distilled water (80 °C) and manually mixed with particles until all the particles were completely covered with the starch based adhesives within 5 min. Meanwhile, the board bonded with commercial binder (UF) was mixed following standard commercial particleboard manufacturing.Then, the mixture was poured into the mould to form a mat with a dimension size of 20.1 cm x 20.1 cm x 0.5 cm, followed by pre-pressing with a cold press for about 2 min. Later, the mat was pressed by hot pressing at a temperature of 165 °C with a pressure of 5 MPa for 15 min. Finally, all the panels were cooled and kept in a conditioning room at a temperature of 25 °C ± 2 °C with relative humidity of 65 °C ± 2 °C for 7 days before further testing were conducted.

Testing and evaluation

Soil burial decay test was performed with a slight modification in sample size and it was conducted in laboratory room in a close container according to BS 1982-2 [17]. All the test specimens in the soil burial and borer test evaluation were cut into dimension 5 cm x 1 cm x 0.5 cm and 3 replicates were prepared from each type of boards. Oven dried weight of all test specimens was recorded before testing. Each sample was weighed at an accuracy of 0.01 g before being placed in the container. The soil burial test was performed in a polyethylene container filled with soil which is had passed through the mesh sieve size of 450 µm. All the specimens were then buried 3 cm deep in the container then were left in the incubator set up at a temperature of 27 °C for four different period times (2, 4, 6 and 8 weeks). All the specimens were removed, cleaned and oven dried in an oven overnight before final weight was recorded. Meanwhile, for borer test, it was carried out based on BS EN 47 [18]. The test specimens were tested in test arena in a close container that has a solid

rubberwood planks attacked by powder post beetles (M. rugicollis). Then the samples were buried in between the two solid rubberwood planks that previously exposed to the insects. Next, the container was sealed and stored in the room without direct sunlight. After 10 weeks exposure, each sample was lightly brushed and dried for the overnight before the final weight was taken.

The fungus test on the test specimens was conducted according to the ASTM D 2017 [19] with slight modification. In this experiment, the samples were exposed to the fungal strains such as G.trabeum Pers.ex.Fr (ATCC No.11539) and Trametes Versicolor (L.ex.Fr.) Pilat. (ATCC No. 42462). Before the testing was conducted, the fungal strains approximately 10 mm was inoculated on petri dish MEA and grown in sterilized glass culture vessels for about two weeks before being exposed to the test samples. Ten replicates for each type of board samples were cut into dimension 25 mm x 25 mm x 9 mm. The incubation of fungi in culture bottles was carried out for twelve weeks in the culture room of controlled environment of 25 °C and 85 % relative humidity. After incubation of 12 weeks, all the test specimens were removed from the culture bottle and lightly brushed before oven dried for overnight in the oven at a temperature of 100 °C. The final weight at nearest 0.01 g was taken after oven dried process. All the samples in the evaluations were calculated as weight loss and expressed as a percentage as in Eq. (1).

$$\text{Weight loss, \%} = \frac{W_1 - W_2}{W_1} \times 100 \qquad \text{Eq. (1)}$$

Where;

W_1 = initial weight before exposure (g)
W_2 = weight after exposure (g)

Statistical analysis

All samples were analysed by using IBM SPSS Statistics sotware for Windows, version 20 and reported as the mean values. The comparison of mean values was tested by using Duncan Multiple Range Test at $p < 0.05$.

RESULTS AND DISCUSSION

Soil burial trend analysis

The weight loss analysis results for the particleboards bonded with native oil palm (OPS_100), modified oil palm starch (MOPS_70:30) and the control board (UF_100) were illustrated in Fig.1. Overall results showed increasing values from week 2 to week 6 except for the particleboard bonded with native oil palm starch (OPS_100) was reduced a value approximately 5.6 %. However, this value increased again to 35.86 % after 8 weeks exposure. Higher starch content maybe was consume as food to microorganisms activity thus encouraged the higher degradation process. The lowest value was found in the samples bonded with modified oil palm starch (MOPS_100) which only obtained a value of 18.62 %.

The addition of boric acid and Nano silicon dioxide (SiO_2) in the modified oil palm samples may attribute to the findings. Higher PVOH content up to 30 % in the starch modification may also affect the results. This statement was in agreement with previous research in soil burial test that used PVOH in the packaging film [9].

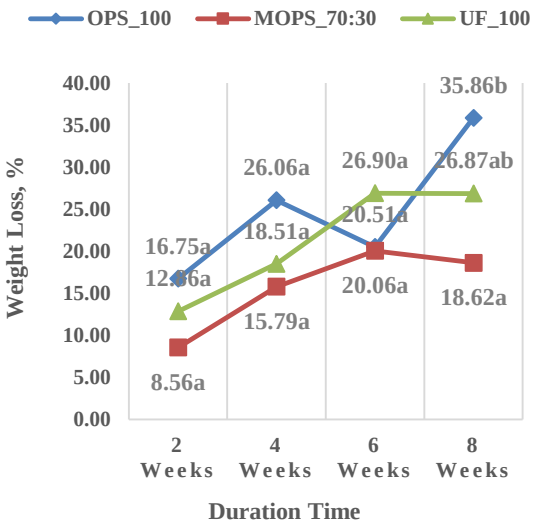

Figure 1. Soil burial trend analysis for particleboards bonded with native Oil palm starch (OPS_100); modified Oil palm starch (MOPS_70:30) and Urea formaldehyde (UF_100). Data is expressed as means; values in parentheses show standard deviations. Values with the same letter are not significantly different ($p < 0.05$).

Statistical analysis also proved that boards bonded with native oil palm starch (OPS_100) and modified oil palm starch (MOPS_70:30) were significantly different to each other.

Borer test analysis

The borer test results had shown no significant different for all samples in weight loss percentage as could be seen in Table 1. The higher value was found in the sample bonded with native oil palm starch (OPS_100) obtained a value of 75.57 %. Meanwhile, the

particleboard bonded with modified oil palm starch (MOPS_70:30) achieved the lowest value (36.55 %) amongst other samples. MOPS_70:30 also proved more resistant approximately 4.38 % from the control sample (UF_100). This may be due to the hydrophilic starch characteristics was covered by using a 3 % of Nano silicon dioxide that was protected the samples from absorbed the moisture which is attributed from the soil.

TABLE 1. Borer test and fungal strains analysis

Samples	Weight Loss (%)		
	Borer Test (10 weeks)	Fungal strains Test (12 weeks)	
		Trametes Versicolor (CV)	*G.trabeum Pers.ex.Fr.* (GTRA)
OPS_100	73.57 (31.77)a	40.57 (13.36)b	38.59 (26.38)b
MOPS_70:30	36.55 (2.36)a	14.33 (8.22)a	16.30 (7.41)a
UF_100	38.15 (0.97)a	17.87 (3.21)a	17.75 (7.10)a

Note: Data is expressed as means; values in parentheses show standard deviations. Values with the same letter are not significantly different ($p < 0.05$). Native Oil palm starch (OPS_100); modified Oil palm starch (MOPS_70:30) and Urea formaldehyde (UF_100).

Fungal strains test analysis

The mean percentage of weight loss due to decay by *C.versicolor* (CV) and *G.trabeum* (GTRA*)* was shown in Table 1. The high weight losses were observed in the samples bonded with native oil palm samples (OPS_100) when exposed to both CV and GTRA fungal strains. The weight loss values obtained were about 40.57 % and 38.59 %, respectively. These findings were supported by statistical analysis that shown a significant different at $p < 0.05$. Higher starch content and hydrophilic characteristics of oil palm starch samples [20] may also contribute to the findings. The board bonded with modified oil palm starch (MOPS_70:30) was shown the lowest values of 14.33 % and 16.30 % when exposed to both CV and GTRA, respectively. The control board (UF_100) was shown less resistance to fungi approximately 24.7 % and 8.90 % as compared to modified oil palm starch (MOPS_70:30) samples when it was exposed to both fungal strains.

CONCLUSION

The presence of Nano silicon dioxide (SiO_2) plus lower starch ratio in the starch modification process successfully influenced the findings. The SiO_2 and boric acid role as a water repellent and antifungal agents thus prevented the microorganism's activity in the final particleboard. The starch-based adhesives made from modified oil palm starch can be suggested as a potential binder in the particleboard manufacturing in the future.

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Persian Abstract

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چکیده

اهداف اصلی این مطالعه بررسی رفتار زیست تخریب تخته خرده چوب های تجربی پیوندی با ۳۰٪ PVOH، ٪70 نشاسته نخل روغن و ۳٪ دی اکسید نانو سیلیکن (SiO2) بوده است. اسید بوریک در ۲٪ به عنوان یک پیوند دهنده متصل به PVOH در نشاسته نخل روغن اصلاح شده به منظور افزایش مقاومت در برابر انبساط نمونه ها اضافه شد. تمام تخته خرده چوب ها با استفاده از تست های کشت خالص، خراش و قارچ بررسی شدند. سپس نمونه ها با تخته خرده چوب با نشاسته نخل نفتی و تجاری اوره فرمالدئید (UF) مقایسه شدند. نتایج نشان داد که تخته خرده چوب با اصلاح PVOH / روغن نشاسته نخل نخاعی مقاوم تر از تخته خرده چوب با نشاسته بومی خود است و بنابراین می تواند به عنوان یک اتصال دهنده بالقوه برای تخته خرده چوب سبز در آینده استفاده شود. SiO2 همچنین اثر قابل توجهی نسبت به نشاسته نخل نخل اصلاح شده در مقایسه با نشاسته نخل نفتی و ترکیبی تجاری داشت.