PRODUCTION OF FIRE-RETARDANT SOUND-ABSORBING PANELS FROM SAGO WASTE

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ZAINAB N, KHAIRUL AIDIL AZLIN AR, NAZLINA S, HASNAIN H, NORHAIZAT S, TENG JX & LAWAI V. 2013. Production of fire-retardant sound-absorbing panels from sago waste. The accumulation of agricultural waste either in solid or liquid form causes environmental concern. In the utilisation of agricultural waste for developing sustainable construction material, cyclotriphosphazene-incorporated sago wastes as pendant groups were prepared and structurally characterised using infrared spectroscope and scanning electron microscope. The chemically-modified sago waste composite was applied with binders and developed as sound-absorbing panels. These panels are a class of organic–inorganic-based material that is fire resistant. The absorption coefficient of panels gave higher values at low (250 and 500 Hz) and medium (2000 Hz) frequencies. The panel was 51% lighter than fibreboard. The function and basic manufacturing of sound-absorbing panels were similar to other products available in the market. The panels showed excellent anti-termite properties.

Keywords: Cyclotriphosphazene, ignition, frequency test, anti-termite

ZAINAB N, KHAIRUL AIDIL AZLIN AR, NAZLINA S, HASNAIN H, NORHAIZAT S, TENG JX & LAWAI V. 2013. Penghasilan panel penyerap bunyi cegah kebakaran daripada hampas sagu. Pengumpulan sisa pertanian sama ada dalam bentuk pepejal atau cecair telah meningkatkan keprihatinan terhadap alam sekitar. Dalam penggunaan bahan buangan pertanian untuk menghasilkan bahan pembinaan mampan, hampas sagu yang bercantum dengan gelang siklotrifosfazena disediakan dan dicirikan menggunakan spektroskop inframerah dan mikroskop imbasan elektron. Komposit hampas sagu yang diubah suai secara kimia dicampurkan dengan bahan pengikat untuk dijadikan panel penyerap bunyi. Panel ini dikelaskan sebagai bahan organik–tak organik cegah kebakaran. Pekali penyerapan panel adalah tinggi pada frekuensi rendah (250 Hz dan 500 Hz) dan sederhana (2000 Hz). Panel adalah 51% lebih ringan daripada papan gentian. Fungsi dan pembuatan asas panel penyerap bunyi adalah setanding dengan produk lain di pasaran. Panel menunjukkan ciri anti anai-anai yang baik.

INTRODUCTION

Sago palm is commonly found in tropical lowland forest and freshwater swamps. Sarawak is currently the world's largest exporter of sago products, exporting 25,000–40,000 tonnes of sago products annually to countries such as Singapore, Taiwan and Japan (Singhal et al. 2008). Mass production of sago produces residues during processing. Approximately 7 tonnes of sago pith waste are produced daily from a single sago starch processing mill (Bujang et al. 1996). The residues are discharged into the river, which eventually cause serious environmental problems. The fibre residues consist of lignin, cellulose and hemicellulose, which can easily generate chemical bonding with electrophiles via hydroxyl groups.

Hexachlorocyclotriphosphazene is an inorganic compound with skeletal nitrogen and phosphorus atoms and is susceptible to nucleophilic substitution. It exhibits unusual thermal properties such as fire retardancy. The incorporation of cyclotriphosphazenes as pendant groups to the backbone of synthetic organic polymers gives a class of organic–

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inorganic polymers that exhibit useful thermal properties such as flame retardancy and self-extinguishability (Muraki et al. 2004, Liu & Wang 2009).

This paper reports on the chemical modification of sago waste by incorporating cyclotriphosphazenes as pendant groups in the sago network via P–O–C bond. The end product is sound-absorbing panel with inherent fire-retardant properties. This study shows promise as one of the environmental solutions to balance the sago waste production of industries.

MATERIALS AND METHODS

Materials

Sago waste was obtained from sago processing mills in Mukah, Sarawak. Samples were sundried, ground, sieved into 1 mm particles and dried in the oven (80 °C). Cyclotriphosphazene was obtained and recrystallised from hexane. Acetone was distilled from calcium hydride under nitrogen. All reactions were performed under nitrogen.

Modification of sago waste

Dried sago waste (10 g) was reacted with sodium metal (2 g) in distilled acetone. The mixture was heated at reflux under nitrogen for 24 hours. Cyclotriphosphazene (2 g) in distilled acetone was added to the mixture. The mixture was stirred and heated at reflux under nitrogen for 2 hours. The mixture was filtered and consecutively washed with ethanol and dried.

Preparation of panels

Selected binder material was chosen based on its plasticity characteristic. Polystyrene (30 g) was dissolved in dichloromethane (200 mL) and mixed with modified sago waste (30 g). The mixture was poured into a metal mould (10.16 cm × 10.16 cm × 2.54 cm) and heated at 120 °C for 3 hours to form panels.

Characterisation of the sample

The infrared spectra were obtained on a Fourier transform infrared spectrophotometer using potassium bromide. Scanning electron microscope (SEM) was used to examine the surface morphology of samples.

Flame ignition test

The ignition test was carried out via open burning on both untreated sago waste and the panel (P1) with and without the presence of kerosene. Surface morphology of P1 before and after ignition was characterised using SEM.

Sound absorption test

Comparison of the sound absorption coefficient (ASTM 1990) was carried out with the current available products such as fibreboard, plywood, carpet and solid wood. All products were fabricated into the same size (10.16 cm × 10.16 cm × 2.54 cm).

Anti-termite activity

The anti-termite activity of test samples was determined using *Heterotermes indicola*. Ten termites were transferred to each vial containing 0.5 g of untreated sago waste (USW), P1 panels and P1 after ignition (P2). For the control experiment, 10 termites each were placed on 0.5 g of wood chips (C1) and in empty vials (C2). The tests were performed in duplicates at room temperature with medium light penetration to produce similar habitation for the termites. The termites were checked for mortality after 24 and 48 hours.

RESULTS AND DISCUSSION

Infrared characterisation

Fourier transform infrared spectra of the USW and P1 are shown in Figure 1. P1 showed significant absorption bands at 1056 cm^{-1} which corresponded to the formation of P–O–C bonds between the sago network and cyclotriphosphazene. The appearance of a peak at 1394 cm^{-1} in P1 was attributed to the presence of $\upsilon_{P\text{-}N}$ delocalised bond in the sago network (Kruszynski et al. 2006). P1, however, showed strong absorption peak at 3446 cm^{-1}, which indicated that the OH groups were still available in the cellulosic materials and substantial for further substitution with cyclotriphosphazenes.

Flame ignition test

The panel of untreated sago waste ignited easily and burned to completion into ashes (Figure 2a).

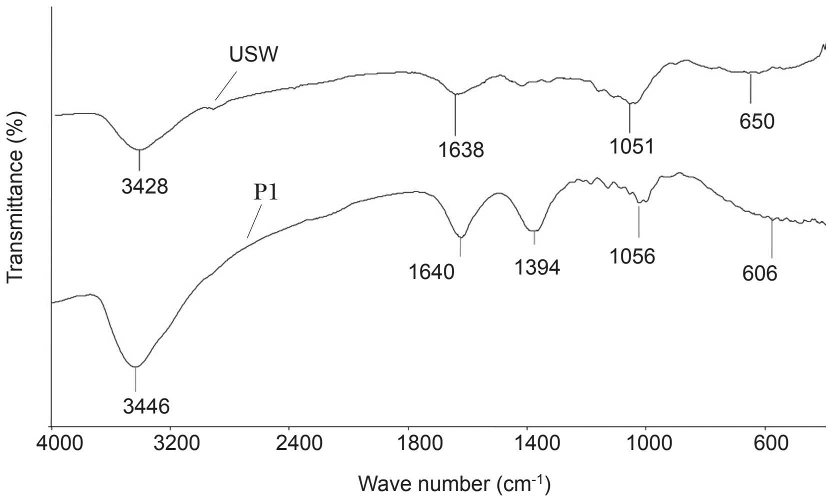

Figure 1 Fourier transform infrared spectra of untreated sago waste (USW) and modified sago waste (P1)

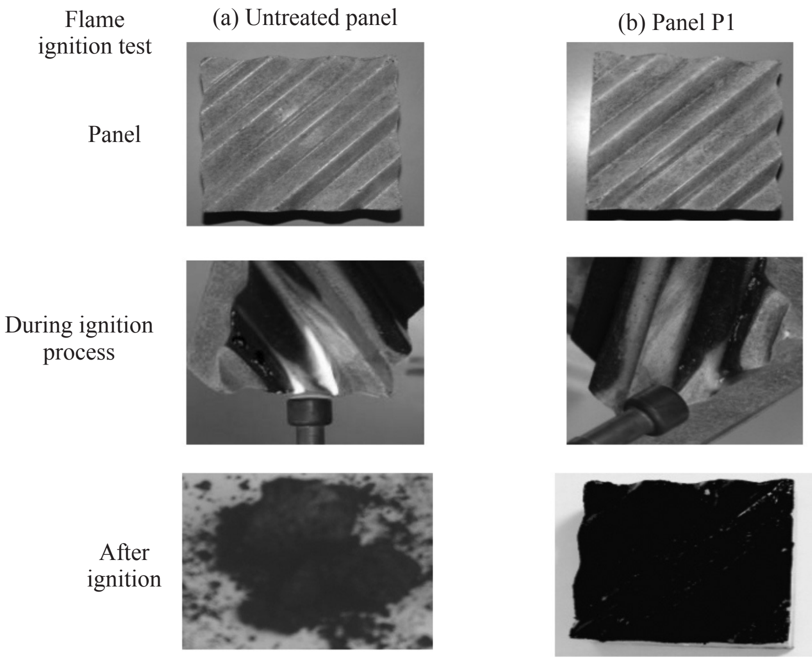

Figure 2 Flame ignition test of (a) untreated panel and (b) modified sago waste (P1)

On the contrary, P1, even after being soaked in kerosene, resisted burning and self extinguished readily when the kerosene was consumed (Figure 2b). The forced ignition of P1 without kerosene only resulted in the formation of chars.

Scanning electron microscope

Scanning electron micrographs of P1 after the flame ignition test showed the formation of chars on the outer layer, while the inner layer was not burned (Figure 3). The cross-section of P1 (Figure 3c) showed two layers with the upper layer (inner layer) similar to Figure 3a and the bottom layer (outer layer), similar to Figure 3b. This was due to the formation of phosphorus chars on the outer layer, which inhibited oxygen from further burning (Liu & Wang 2009). The ignition caused the breakdown of the P–O–C bonds which yielded high amounts of phosphorus char that inhibited contact of air with the inner part of the panel for further ignition (Liu & Wang 2009). The incorporation of cyclotriphosphazenes into the chain structure of cellulose and lignin of the sago waste via hydroxyls groups increased the thermal and flame resistance of the products.

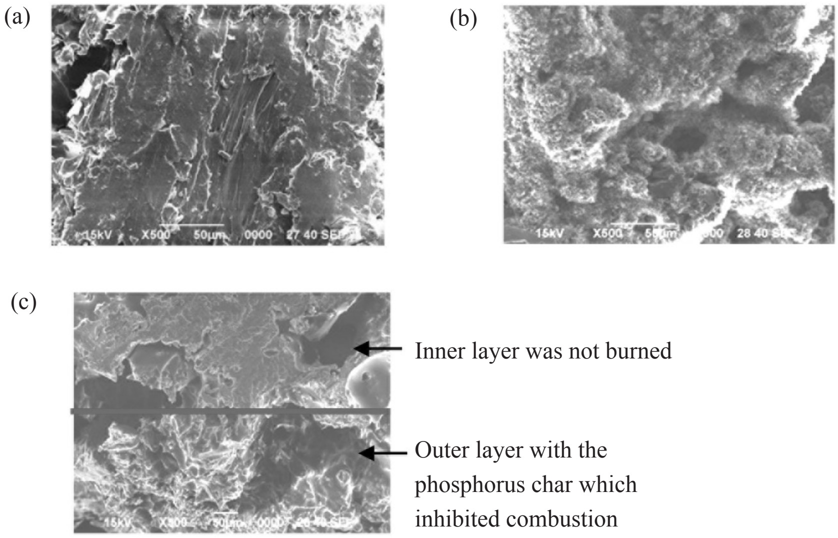

Figure 3 Scaning electron micrographs of (a) P1 before ignition, (b) P1 after ignition and (c) cross-section of P1 after the flame ignition test

Installation of panels

The panel was designed for simple installation to the wall. Aluminum or wooden frame was used as a holder for panels to be arranged accordingly (Figures 4a–b). The panel was also designed with an interchangeable casing made from thermosetting plastic with various modern and contemporary patterns (Figures 4c–d). The casing could function as a double-layer silencer and sound filter.

Sound absorption test

P1 panel gave a mean sound absorption of 0.716, which was higher than the other samples but equivalent to fibreboard (Table 1). However, in comparison with other samples, the absorption coefficient of P1 showed significantly higher values at low (250 and 500 Hz) and medium (2000 Hz) frequencies. This indicates that P1 panel is suitable for use in medium frequency. The test also showed that P1 panel had better sound absorption coefficient than other samples. The weight of P1 was 51% lighter than fibreboard with the same size and thickness.

Anti-termite properties

Sago waste consists of a high percentage of cellulose, which is prone to termite attack. The vials containing P1, P2 and C2 showed significant activities against *H. indicola* (Table 2). All termites were dead after 24 hours due to cellulose unavailability as a source of food. However, USW and C1 showed zero lethality due to cellulose availability from both sago waste and wood. The observations in P1 and P2 indicated that treated sago waste could not be used by termites as a source of food, thus the anti-termite activity.

CONCLUSIONS

Sound-absorbing panels P1 was successfully developed using sago waste. The modification of sago waste via incorporation with cyclotriphosphazene had made the panel fire resistant. The panels had shown excellent anti-termite properties. This indicates its potential to be commercialised especially in the music industry. These panels do not require high technology and can be mass produced.

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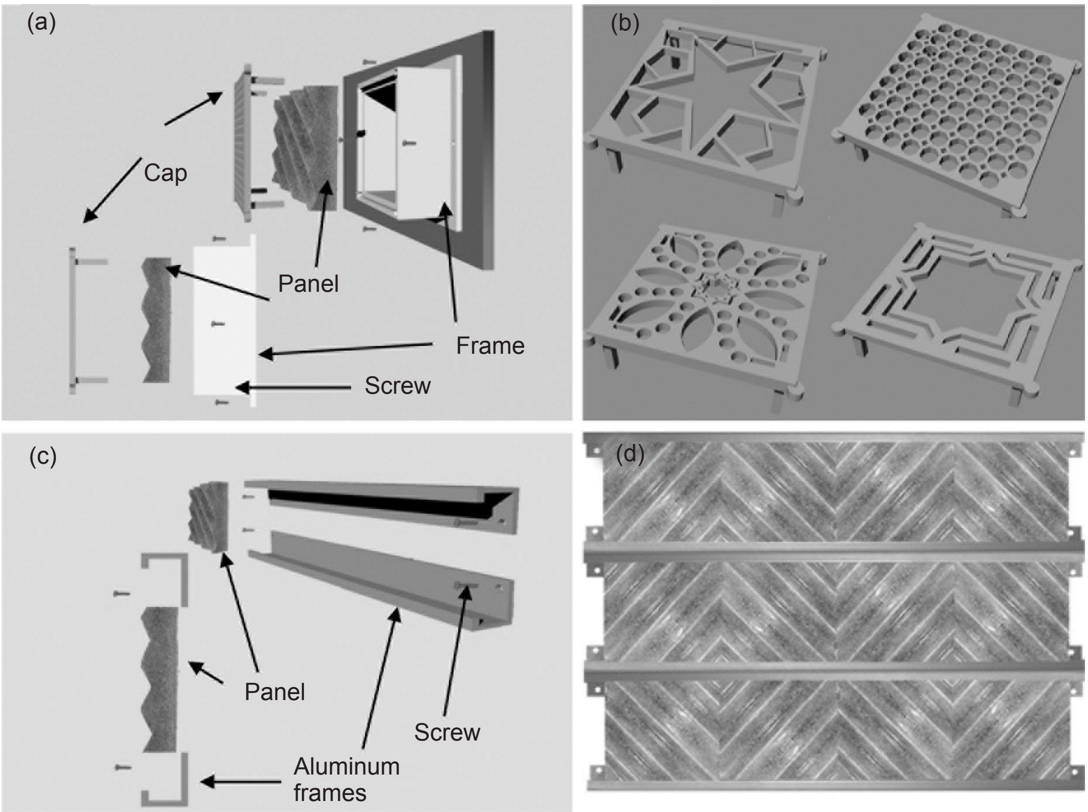

Figure 4 Mounting and installation of P1

Table 1 Comparison of sound absorption coefficients of various sound-absorbing panels

Sample	Frequency (Hz)					
	250	500	1000	2000	4000	Mean
Sago waste panel (P1)	0.564	0.718	0.710	0.873	0.715	0.716
Fibreboard	0.525	0.612	0.702	0.804	0.937	0.716
Plywood	0.203	0.510	0.794	0.832	0.895	0.647
Carpet	0.249	0.346	0.509	0.808	0.922	0.566
Solid wood	0.202	0.322	0.733	0.684	0.625	0.513

Table 2 Anti-termite activities of panels

Sample	Day	Average of mortality
USW	1	0
	2	0
P1	1	10
P2	1	10
C1	1	0
	2	0
C2	1	10

USW = untreated sago waste, P1 = panel before ignition, P2 = panel after ignition, C1 = vial with wood chip, C2 = empty vial

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