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Resistance of Wood Plastic Composites Having Silica Filler to Subterranean Termite

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ABSTRACT

Rubberwood (*Hevea brasiliensis*) has excellent physical and mechanical properties and is one of the most widely used species in Southeast Asia. However, it has poor resistance to subterranean termite attacks due to its high sugar and starch contents. The objective of this study was to evaluate the termite resistance of experimental wood-plastic composite (WPC) panels manufactured from rubberwood flour, polyethylene terephthalate, and silica in three different weight ratios (1/2/7, 1/3/6, and 1/4/5). The panels were exposed to *Coptotermes curvignathus* subterranean termites in a no-choice test under laboratory conditions based on Indonesian standards. Solid rubberwood used as control samples presented poor resistance, exhibiting 23.1% weight loss due to subterranean termite attack, as indicated by low termite mortality and high wood weight loss. In contrast, the WPC samples demonstrated extreme resistance, with weight loss ranging from 0.19% to 0.23%. Based on the findings of this study, the high termite mortality and overall low mass loss of the samples indicate that such manufactured panels could provide a high level of protection with regard to Indonesian standards.

Keywords: rubberwood, silica, subterranean termite, wood plastic composites

1. INTRODUCTION

Wood supply is increasingly sourced from plantation forests, as natural forestland does not fully meet the industry's wood demand. Forest plantations provide most of the products and services provided by natural forests (Zhang and Stanturf, 2008). In general, logs in tropical and subtropical areas are predominantly harvested from fast-growing tree species with short rotation cycles of less than ten years old or from timber species that are harvested as the strength of the trees declines. Timber from such species primarily consists of sapwood and a high percentage of juvenile wood, resulting in inferior physical and mechanical properties, as well as high

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susceptibility to biodeterioration, specifically termite damage, compared to wood from older trees (Hadi *et al*., 2015).

Rubberwood (*Hevea brasiliensis* Muell. Arg) plantations are harvested at 30-year intervals as latex production declines, and replantation is performed for continued production and sustainability. Rubberwood is moderately dense (0.60 g/cm^3) and is light in color, which is favorable for furniture production. Although rubberwood has moderate physical and mechanical properties, it is highly susceptible to biodeterioration due to its high carbohydrate content. In Indonesia, subterranean termite attacks classify rubberwood as having poor resistance, placing it in class V (Arinana *et al*., 2012), the least resistant class according to the Indonesian standard (SNI, 2014). Furthermore, Arinana *et al*. (2022) stated that rubberwood was the preferred wood species for baiting tests because of its susceptibility to subterranean termites among the other tested plantation wood species: mangium (*Acacia mangium*), sengon (*Falcataria moluccana*), jabon (*Anthocephalus cadamba*), manii (*Maesopsis eminii*), mahogany (*Swietenia mahagoni*), and pine (*Pinus merkusii*).

Subterranean termites are significant timber degraders in the tropics and North America, attacking all types of wood and wood-based materials (Chotikhun *et al*., 2018; Gao and Du, 2015). Certain plant and wood are toxic to subterranean termites (Ahmed *et al*., 2020; Fatima *et al*., 2021; Syofuna *et al*., 2012). For instance, methanol extracts of *Madhuca utilis* heartwood from Malaysian timber produced high mortality rates in *Coptotermes gestroi* and *Coptotermes curvignathus* (Kadir, 2017). Similarly, *Guibourtia tessmanii* (harms) J. Léonard (Kévazingo) bark extracts from Gabon act as anti-termite agents (Nkogo *et al*., 2022). Additionally, proanthocyanidin-rich extracts from *Pinus radiata* bark have been found to deter termite feeding (Mun and Nicholas, 2017). Cu nanoparticles and plant extracts have also shown promise against termites and decay fungi (Shiny *et al*., 2019). Furthermore, Nandika *et al*. (2023) reported that rubberwood impregnated with catechin from gambir (*Uncaria gambir* Roxb.) increased the wood's resistance to *Aspergillus chevalieri*.

In a study conducted by Hadi *et al*. (2020), mangium (*A. mangium*) and sengon (*F. moluccana*) wood samples exposed to smoke from salam (*Syzygium polyanthum*) wood enhanced their resistance to subterranean termite (*C. curvignathus* Holmgren) attack under laboratory conditions. Arsyad *et al.* (2020) reported that bamboo vinegar treatment could improve the resistance of rubberwood to the subterranean termite *C. curvignathus* Holmgren. Another study found that *Cinnamomum parthenoxylon* wood vinegar has anti-termite activity, specifically against subterranean termites (Adfa *et al*., 2020). In addition to these plant and wood extracts, other techniques, including environmentally friendly wood modification methods, have been extensively investigated over the last several decades. For instance, wood modified with methyl methacrylate (Hadi *et al*., 2018) was used to improve its resistance to termite attacks. However, methyl methacrylate, a monomer, did not react chemically with the samples. Similarly, polystyrene-impregnated glued-laminated lumber exhibited the highest durability, followed by control glulam and solid wood after exposure to subterranean termites in the field (Hermawan *et al*., 2024).

Wood plastic composite (WPC), a relatively new composite material prepared from wood flour, wood particles, or wood fibers combined with thermoplastic materials under specific heating and pressure conditions, shares similar characteristics with wood modification methods aimed at eliminating biodeterioration. It is a well-established fact that WPCs have relatively high resistance to termite attack. WPC materials can be placed in contact with the soil, either as structural members or building components, and may have the potential to limit termite damage in buildings (Gardner and Bozo, 2018). They can be produced from recycled materials, and several additives can improve their properties (Delviawan *et al*., 2019). For instance, adding nanoclay to WPC can improve water absorption properties and enhance the samples' performance (Seo *et al.*, 2019). Additionally, WPC samples made from a mixture of wood chip, polyethylene (PE), and some additives ($CaCO_3$, coupling agent, and zinc stearate) presented better mechanical properties and dimensional stability than the tested cement paver blocks used as a control (Yang, 2019). However, WPC was reported to experience weight loss (WL) after a 50-day baiting test in nature (Nuryawan *et al.*, 2020). Therefore, despite WPCs having several advantages, such as ease of maintenance, high durability, and long service life, they also have certain disadvantages, such as hydrophilicity, flammability, limited weathering resistance, flammability, and the thermal expansion of plastics (Wang *et al.,* 2021).

There is an increasing demand for WPCs due to their excellent dimensional stability, hardness, finishing, and enhanced appearance for use as raw materials in applications such as decking, railings, sidings, doors/windows, roof shingles, and flooring (Yang *et al.*, 2018). The evaluation of the biological performance of WPCs has become a major interest as their demand increases as an alternative material to treated and untreated wood units (Bari *et al.*, 2015, 2017). Recent research on WPC durability has focused on understanding the mechanisms contributing to various degradation issues and methods to improve durability. Fungal decay of wood components can also occur in WPCs exposed to severe environmental conditions such as tropical environments (Ibach *et al.*, 2013). Termites are insects capable of degrading plastics using their gut microbiota. The termite gut exhibits substantial microbial diversity, but only a few have the potential to degrade bioplastic materials such as WPCs (Kumar *et al.,* 2022). Termite attacks on WPCs have been reported in laboratory tests (Xu *et al.*, 2015). However, acetylation pretreatment of wood flour for WPC enhanced resistance to subterranean attacks in a field exposure in Bogor, Indonesia, for 2.5 years (Ibach *et al.*, 2007). Additionally, aged WPC specimens that were exposed to termites, *Nasutitermes nigriceps*, for 15 and 30 days have shown reduced mechanical properties (López-Naranjo *et al.,* 2013). Furthermore, Lopez *et al.* (2020) found that WPC produced by compression of *Pinus elliottii* wood, recycled thermoplastics, and polypropylene at a ratio of 50/50 was highly resistant to *Nasutitermes corniger* and *Cryptotermes brevis.*

Portland cement, rich in silica, is typically used to manufacture cement-based panels. Garcia *et al.* (2012) determined that wood wool cement boards (WWCB) manufactured from different wood species are resistant to *Microcerotermes losbañosensis* Oshima and *Cryptotermes dudleyi* Banks under laboratory conditions. The WWCB was also highly resistant to subterranean termites in field tests, with relatively little termite damage, except for initial termite feeding on the board during the 8-year exposure period. Deka and Maji (2012) found that silica nanopowder significantly improved the tensile and flexural properties, thermal stability, hardness, and flame and water resistance of WPC panels. Chotikhun *et al.* (2022) manufactured WPC panels by using rubberwood (*H. brasiliensis* Muell. Arg), evaluated some of its properties, and found that these products could have the potential to be used as value-added environmentally friendly products for various applications.

Currently, little information is available on the termite resistance of silica-amended WPCs. Therefore, the objective of this study was to evaluate the resistance of termites to silica-supplemented experimental WPC panels made using rubberwood particles in laboratory feeding trials.

2. MATERIALS and METHODS

2.1. Manufacture of wood plastic composite samples

Rubberwood (*H. brasiliensis* Muell. Arg) lumber was obtained from Surat Thani, cut into small pieces, and oven dried at 100℃ to a moisture content (MC) of 8%–12% before being ground into a powder (18–40 mesh) with a density of 0.62 g/cm^3. Polyethylene terephthalate (PET) from plastic bottle waste was shredded to approximately 0.4 cm length, with a density of 1.38 g/cm^3, and silica (18–40 mesh) with a density of 1.60 g/cm^3 was supplied by Huatanon (Surat Thani, Thailand).

WPC specimens were prepared by mixing wood powder, recycled plastic, and silica at three different ratios on a mass/mass/mass basis, as listed in Table 1. A previous study showed that WPC panels could maintain a homogeneous mixture (Chotikhun *et al*., 2022). All raw materials were mixed for 5 to 10 minutes in a mixer at a temperature of 250℃–260℃, as shown in Fig. 1. The mixture was then poured into a frame measuring 30 cm long × 30 cm wide × 1.5 cm thick before being compressed in a hot press at 5.5 MPa and 250℃ for 10 min. The mats were cooled for 20 min and then stored in a control room at a temperature of 25 ± 2℃ and relative humidity of 65 ± 2% before being cut into 2 cm by 2 cm squares and 1.5 cm thick samples. Six replicate panels were prepared for each WPC type. Two samples of solid rubberwood (MC % = 10%–12%) specimens were also prepared as control samples.

2.2. Durability test of the samples against termites

The samples were exposed to subterranean termites (*C. curvignathus* Holmgren) under laboratory conditions,

Table 1. Composition of mixtures used to produce WPC panels for termite testing (% mass/mass basis)

Component	WPC-1	WPC-2	WPC-3
Wood	10	10	10
PET	20	30	40
Silica	70	60	50

WPC: wood plastic composite, PET: polyethylene terephthalate.

according to the Indonesian standard SNI 7207-2014 (SNI, 2014). Each WPC specimen was placed in a glass chamber with 200 g of sterilized sand and water to achieve a MC 7% less than the water-holding capacity of the sand. Two hundred healthy and active termite workers from a subterranean laboratory colony of *C. curvignathus* Holmgren were added to each container as depicted in Fig. 2.

The containers were incubated in the dark, at temperature levels of 25℃–30℃ and relative humidity of 80%–90% for 4 weeks. The chambers were weighed weekly and water was added if the MC of the sand decreased by 2% or more.

At the end of the test period, the samples were cleaned, weighed, oven-dried at 100℃, and weighed again. The MC of wood, termite mortality, protection level of the WPC, termite feeding rate, and wood resistance class based on the percentage of wood WL were evaluated using the following equations: The MC and wood WL were determined as described by Thybring (2013).

$$MC = (W1 - W0 - W2) / (W0 - W2) \times 100\% \quad (1)$$

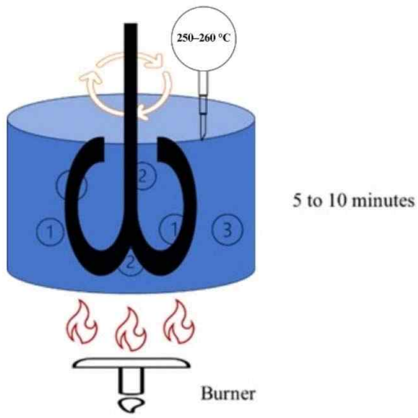

Fig. 1. A schematic representation of the mixer used to homogenize the raw materials of the WPC panels. WPC: wood plastic composite.

Fig. 2. A no-choice WPC termite test against subterranean termites in the laboratory. WPC: wood plastic composite.

Where W0 is the oven-dried weight of the specimen, W1 is the air-dried weight of the specimen, and W2 is the weight of the PET and silica content; for the control wood, it was zero.

$$\text{Termite mortality} = (T1 - T2) / T1 \times 100\% \tag{2}$$

Where T1 and T2 are the number of live termites before and after the test, respectively.

The protection levels of the test specimens against termite attacks were rated according to Table 2, as described in a previous study by Hadi *et al.* (2016).

Termite mortality was assumed to be linear with time, and the feeding rate was calculated using the following Equation (3):

Feeding rate (μg/termite/day) =
(Weight of wood eaten; μg) /
(Average number of living termites during the test) /
(Number of days in the test period) (3)

$$\text{WPC weight loss (WL)} = (W3 - W4) / (W3 - W2) \times 100\% \tag{4}$$

Where W3 and W4 are the oven-dried weights of specimens prior to the test (mg) and after the test (mg), respectively.

The resistance class of wood against subterranean termites was determined by the WL value according to SNI 7207-2014 (SNI, 2014; Table 3).

2.3. Microstructure evaluation of the samples

Scanning electron microscopy (SEM), FEI Quanta 250 (Thermo Fisher Scientific, Waltham, MA, USA), was employed to determine the microstructure of the samples. Images were captured from the longitudinal sections of the WPC samples and the tangential section of the rubberwood sample. Each sample was first coated with a thin gold layer and subsequently observed using

Table 2. Rating system of protection level against termite attack

Rating	Criteria
10	No attack or a few nibbles present
9	Small tunnel on the surface, < 3% of the cross-sectional area affected at any location
7	Termite attack affects 10%–25% of the cross-sectional area at any location
4	Termite attack affects > 50% of the cross-sectional area at one location, but the specimen has not failed
0	Failure

Adapted from Hadi *et al.* (2016) with CC-BY.

Table 3. Resistance classes categorized against subterranean termite attacks

Resistance class	Termite resistance	WPC weight loss (%)
I	Very resistant	< 3.52
II	Resistant	3.52–7.50
III	Moderately resistant	7.50–10.96
IV	Poorly resistant	10.96–18.94
V	Very poorly resistant	> 18.94

WPC: wood plastic composite.

an SEM instrument set to 15 kV.

2.4. Data analysis

The effects of board type on response variables such as wood WL (%), termite mortality (%), and termite feeding rate were analyzed using a completely randomized design. Solid rubberwood, WPC-1, WPC-2, and WPC-3 were considered the four board types. Analysis of variance (ANOVA) indicated the significant differences among the four board types, and further analysis was conducted using Duncan's multiple range tests (significantly different at $p \leq 0.05$). Data were analyzed using Microsoft Excel 365® (Microsoft, Redmond, WA, USA) and SPSS Statistics version 22 (IBM, Armonk, NY, USA).

3. RESULTS and DISCUSSION

3.1. Physical properties of the samples

The morphology of the WPC and solid rubberwood was determined using SEM. Each sample was first coated with a thin gold layer and subsequently observed using an SEM electron microscope (FEI Quanta 250, Thermo Fisher Scientific) at 15 kV. SEM images of the WPC samples are shown in Fig. 3.

Fig. 3 illustrates that WPC-1, which contained the lowest PET content (20% w/w), had more gaps than WPC-2, which had a higher PET content. However, at the highest PET content, WPC-3 exhibited very limited structural gaps. As PET functions as a matrix in this case, a higher PET content can facilitate the homogeneous structure in the generated WPC. This homogeneous structure of the WPC was directly related to its density. In this study, the recorded densities for rubberwood, WPC-1, WPC-2, and WPC-3 were 0.71, 1.37, 1.36, and 1.53 g/cm^3, respectively.

The initial MC of solid rubberwood (11.6%) was within the range of equilibrium MC in the Bogor area (11%–18%; Kadir, 1973). Meanwhile, due to the higher weight ratio (90%) of PET and silica, which are hydrophobic materials, the generated WPCs exhibited low MC values (1.36%–1.53%). These low MC values and the material compositions of WPCs exhibit an advantage by

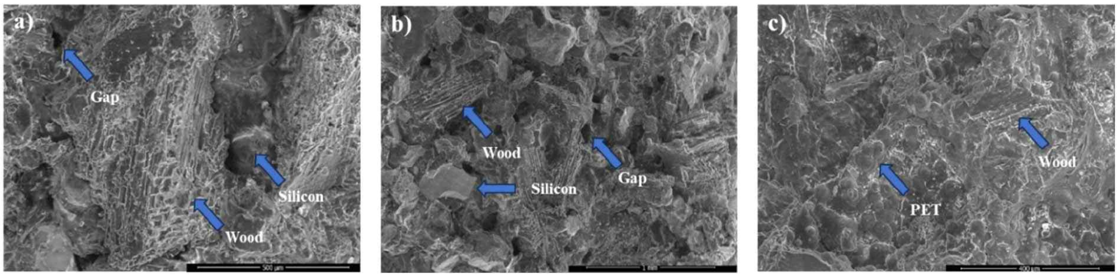

Fig. 3. SEM images of WPC samples. (a) WPC-1, (b) WPC-2, and (c) WPC-3. SEM: scanning electron microscopy, WPC: wood plastic composite.

showing particularly good resistance to biodeterioration attacks.

The ANOVA and multi-range Duncan's test results are presented in Tables 4 and 5, respectively. The density of solid rubberwood (0.71 g/cm^3) was within the range of common wood densities, according to MOEF (2020). The three WPCs had a higher density (average 1.42 g/cm^3) than solid wood samples. Based on the ANOVA results shown in Table 4, all treatments significantly influenced board density. The values of the solid wood differed from those of the WPCs, whereas the three WPC types were not statistically different, as shown in Table 5.

Table 4. ANOVA of termite mortality, board percent weight loss, board protection level, and termite feeding rate

Response	Type of board
Board density	**
Board moisture content	ns
Termite mortality	**
Board mass loss	**
Board protection level	**
Termite feeding rate	**
Board weight loss	**

** Highly significantly different ($p \leq 0.01$), ns is not significantly different.
ANOVA: analysis of variance.

3.2. Termite mortality

The average and SD values of termite mortality, feeding rate, board protection level, board percent WL, and board resistance class are shown in Table 6. Rubberwood is considered to be poorly resistant to termite attacks based on Indonesian standard 7207-2014 (SNI, 2014) and research by Arinana *et al*. (2012, 2022).

Termite mortality among workers exposed to solid rubberwood was low (3.7%), indicating that the test conditions were suitable for termite development. The board type significantly affected termite mortality (Table 4), with solid wood showing significantly higher termite mortality compared to the WPC samples. Termite mortality did not differ significantly among the three WPCs, with all samples exhibiting 100% termite mortality. The WPCs contained 90% plastic and silica, leaving little wood for the termites to feed on. In the no-choice test, few termites survived as all eventually died.

Table 5. Duncan's multiple range tests of wood species for density, moisture content, mortality, protection level, feeding rate, and weight loss.

Parameter	Solid wood	WPC-1	WPC-2	WPC-3
Board density	a	b	b	c
Board moisture content	b	a	a	a
Termite mortality	a	b	b	b
Board protection level	a	b	b	b
Termite feeding rate	b	a	a	a
Board weight loss	b	a	a	a

a–c Values followed by the same letter within the same row are not statistically different according to Duncan's multiple range test.
WPC: wood plastic composite.

Table 6. Termite mortality, termite feeding rate, board protection level, board weight loss, and board resistance class of the samples

Type of board	Termite mortality (%)	Termite feeding rate (μg/termite/day)	Board protection level	Board weight loss (%)	Board resistance class
Solid wood	3.7 (1.1)	237 (37)	4 (0)	23.10 (3.50)	4.8 (0.4)
WPC-1	100 (0)	8.3 (1.7)	10 (0)	0.23 (0.06)	1.0 (0.0)
WPC-2	100 (0)	6.7 (1.2)	10 (0)	0.20 (0.02)	1.0 (0.0)
WPC-3	100 (0)	7.7 (3.0)	10 (0)	0.19 (0.08)	1.0 (0.0)

Values in parentheses are SDs.
WPC: wood plastic composite.

3.3. Termite feeding rate

Termite feeding rate was affected by panel type. The solid rubberwood had the highest feeding rate (237 μg/termite/day), which was significantly higher than that of the WPCs boards (average 7.6 μg/termite/day). Similar to termite mortality rates, the termite feeding rates did not differ significantly among the three WPCs samples. Notably, solid rubberwood was severely damaged by the termites, whereas none of the WPCs were damaged (Fig. 4).

The solid rubberwood had the highest feeding rate, which was possibly related to the very low termite mortality value of 3.7%. Arinana *et al.* (2012) mentioned that the termite feeding rate of solid rubberwood reached 79 μg/termite/day with termite mortality of 21%. The higher feeding rate of solid rubberwood in this study was due to low termite mortality. Conversely, termite mortalities were 100% for the WPC boards because they were composed of 90% plastic and silica and only 10% wood.

3.4. Protection level of the panels

The protection levels of the samples were assessed based on the overall damage observed on each test

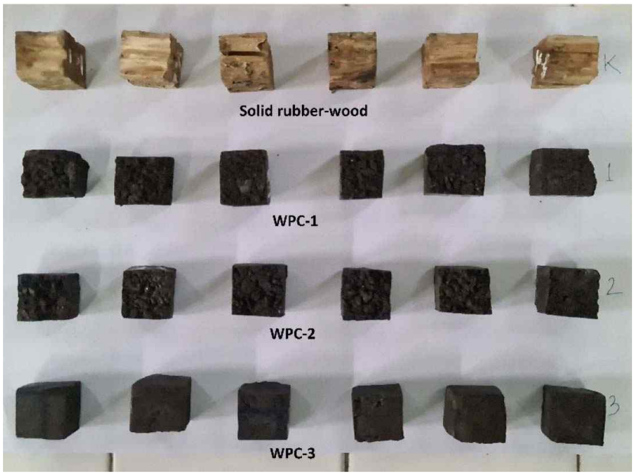

Fig. 4. Test specimens exposed to subterranean termites. WPC: wood plastic composite.

board. The protection level of the test board was affected by the type of board, as shown in Table 4. Further analysis from Table 5 shows that the solid rubberwood, which experienced severe termite attack (protection level 4, the second-lowest protection level), differed significantly from all the WPC specimens, which achieved protection level 10, the highest protection level. The test boards showed minimal signs of termite damage; therefore, they achieved the highest protection level. However, extended testing periods, including field trials, are recommended for WPCs, as noted by Garcia *et al*. (2012) and Ibach *et al*. (2007). The protection level observed for solid rubberwood aligns with findings from other studies, including those by Arinana *et al*. (2012, 2022) and MOEF (2020).

3.5. Percent weight loss and resistance classification of the samples

The percentage WL of each board type was influenced by its composition, as shown in Table 4. According to Table 5, the solid rubberwood exhibited a significantly higher WL compared to all three WPCs, which did not differ significantly from each other. The WL of solid rubberwood samples was 23.1%, which aligns closely with findings by Arinana *et al*. (2012), who reported a value of 21.0% and suggested rubberwood as a suitable reference control. In contrast, WPCs experienced minimal WL, approximately 0.21%, indicating their high resistance to termite attacks. According to SNI (2014), solid rubberwood is included in resistant class 5, indicating very poorly resistant, while WPCs are classified as highly resistant. These results are consistent with Garcia *et al*. (2012), who demonstrated the high resistance of WWCB against subterranean Philippine termite attacks in laboratory and field tests. Extending the field-testing period for WPCs, similar to Garcia *et al*. (2012), who conducted an 8-year test, would further validate their excellent resistance to termite attacks.

4. CONCLUSIONS

Termites are the predominant soil insects capable of wood degradation and notably, they can also degrade plastics and polymer-based materials. In this study, solid rubberwood samples showed little resistance to subterranean termite attacks, as indicated by low termite mortality, high wood WL, and low wood protection, resulting in their classification as very poorly resistant (class 5) according to the Indonesian standard. In contrast, silica-based WPCs were associated with complete termite mortality (100%), low board WL (0.19% of WPC-3 sample), and high protection level, resulting in their classification as very resistant (class 1) according to Indonesian standards. However, future field-testing over extended periods is required to validate these findings further. The WPC used in this study were composed of a mixture of a low percentage of rubberwood (*H. brasiliensis* Muell. Arg) bonded with PET, with silica as a filler and exhibited high resistance according to Indonesian standard SNI 7027-2014. Based on these results, these materials show promise for various applications, including direct outdoor use in contact with the ground.

CONFLICT of INTEREST

No potential conflict of interest relevant to this article was reported.

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