Biological Decay and Termite Resistance of Post-Treated Wood-Based Composites under Protected Above-Ground Conditions: A Preliminary Study after 36 Months of Exposure

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Five kinds of commercially available wood-based composites (softwood plywood, hardwood plywood, medium density fiberboard, oriented strand board, and particle board, hereinafter abbreviated as SWP, HWP, MDF, OSB, and PB, respectively) post-treated with alkaline copper quat (ACQ) and copper azole (CA) were exposed to decay and subterranean termite activity under protected above-ground conditions in a southern Japan field test site for three years. Variables examined included comparisons of untreated and treated wood-based composites, preservative type, and retention levels. Both biological attacks developed with time. Termite damage started earlier, and the severity of attack was higher than decay fungi. Untreated MDF and PB were highly resistant to field conditions during the 36 months. Untreated OSB, HWP, and SWP were the least resistant composite types. ACQ and CA treatments significantly improved the durability of the wood-based composites resulting in 64.4%, 47.9%, and 22.5% higher termite ratings when compared to their untreated controls for OSB, HWP, and SWP, respectively. Preservative types and increased retentions did not significantly affect the decay and termite ratings. These results suggest that ACQ and CA post-treatments at exterior protected and unprotected (K3) and double K3 retention levels significantly improved durability of wood-based composites tested but failed to provide full protection.

Keywords: Above-ground use; Post-treatment; Termite resistance; Wood-based composites

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INTRODUCTION

Wood-based composites have been increasingly utilized over the past few decades, mostly replacing solid lumber in non-structural and structural applications in the construction industry (Laks 2002; Kirkpatrick and Barnes 2006). Since these composites are prone to biodegradation and biodeterioration when used in outdoor conditions and when in contact with the ground, proper protection is important to ensure a long service life (Gardner *et al.* 2003). While their decay performance is better, untreated softwood plywood, particleboard, and oriented strand board were found to have suffered from termite attack at the end of a five-year field test in southern Japan. It was concluded that untreated wood-based composites are not durable enough even in a protected above-ground exposure setup (Tsunoda 2008). Therefore, such composites need to be protected by various methods during or after manufacturing. Both copper azole (CA) and alkaline copper quat (ACQ) are free of arsenic and chromium and are considered to be environmentally acceptable alternatives to CCA worldwide, and therefore became subjects of this study. Each method, however, presents its own advantages and disadvantages in terms of effects on the final product or manufacturing process as well as preservative distribution. The most practical method is considered to be a post-manufacturing treatment via dipping, spraying, brushing, or vacuum pressure. Unfortunately, there has been a lack of hard data on the biological performance of preservative-treated wood-based composites under actual service conditions, which could be attributed to failure to use an appropriate test method for evaluating and comparing field test data. The protected above-ground exposure test setup used in this study was recently developed and established as a way to simulate the temperature and relative humidity profile of crawl spaces of Japanese homes (Tsunoda *et al.* 2000; Grace *et al.* 2000; Morris *et al.* 2003).

The objective of this study was to determine biological performance of wood-based composites post-treated with ACQ and CA under protected above-ground conditions in a field test.

EXPERIMENTAL

Wood-based Composites

Specimens (100 mm x 100 mm x thickness) consisted of commercially available structural-use softwood plywood (SWP) [oven-dried density (o.d.d): 0.59 g/cm^3; thickness (mm): 12.1], hardwood plywood (HWP) [o.d.d: 0.50 g/cm^3; thickness (mm): 11.7], medium density fiber-board (MDF) [o.d.d: 0.71 g/cm^3; thickness (mm): 12.0], oriented strand board (OSB) [o.d.d: 0.63 g/cm^3; thickness (mm): 12.7], and particleboard (PB) [o.d.d: 0.71 g/cm^3; thickness (mm): 11.9]. The manufacturing details of these wood-based composites tested are given in Table 1.

Table 1. Manufacturing Details of Wood-based Composites Tested

Composite	Raw material	Orientation & construction	Adhesive
SWP	*Larix* spp.	0º/90º, 5 plies (2/2/3/2/3 mm)	Boiled-water resistant exterior type phenol-formaldehyde
HWP	Dipterocarpaceae	0º/90º, 5 plies (2/3/2/3/2 mm)	Boiled-water resistant exterior type phenol-formaldehyde
MDF	Hardwood fibers	Random, 3 layered (2/8/2 mm)	Melamine-urea-formaldehyde
OSB	Aspen	Random, 3 layered (3/6/3 mm)	Phenol- formaldehyde
PB	Hard/Softwood mix	Random, 3 layered (3/6/3 mm)	Melamine-urea-formaldehyde

The specimens were double-coated with a two-component epoxy resin on each cut end, in order to simulate penetration characteristics of a full-size composite product, and conditioned at 60 ± 2ºC for 72 h prior to preservative treatments.

Preservatives and Target Retentions

Alkaline copper quaternary (ACQ) and copper azole (CA), supplied respectively by Koshii Preserving Co. Ltd. (Osaka, Japan) and Xyence (Isezaki, Gunma, Japan), were used in this experiment. Because the solution uptakes were expected to vary with the permeability and density profiles of the wood-based composites, a series of treatments with water were performed in advance to achieve target retentions. The target retentions were selected as K3 according to Japanese Agricultural Standard JAS 1083 (2007) and double K3, which indicates 2.60 and 5.20 kg/m^3 retentions for ACQ, and 1.0 and 2.00 kg/m^3 retentions for CA. Preliminary studies and laboratory data obtained from decay and termite tests suggested that there was a necessity for higher retentions in order to improve biological resistance of post-treated SWP, HWP, and OSB (Tascioglu and Tsunoda 2010a,b). The pH values of experimental solutions were approximately 9.6 and 8.8 for ACQ and CA, respectively.

Treatments

Vacuum impregnation was used to deliver the ACQ and CA solutions into the wood-based composites under ambient conditions. Composite specimens were positioned in a cylindrical glass container, and an absolute pressure of 6 kPa was applied in the absence of treatment solution. The solution was then introduced into the container while the specimens were under vacuum. The soaking durations were adjusted according to the permeability of each wood-based composite type. The retention values of ACQ and CA in the treated materials were calculated based on the weight-gain method. The treatment schedules used were as follows: for SWP, 30 min of dry vacuum followed by 60 min of wet vacuum; for HWP, 30 min of dry vacuum followed by 20 min of wet vacuum; and for MDF, OSB, and PB, 10 min of dry vacuum followed by 1 min of wet vacuum. Based on the treatment schedules mentioned above, the mean water retentions of the composites were recorded as 153, 193, 398, 339, and 364 kg/m^3 for the SWP, HWP, MDF, OSB, and PB specimens, respectively (Tascioglu and Tsunoda 2010a). Thirteen specimens of each composite type and retention level combination were treated one time each. A total of 20 charges were carried out to acquire 260 specimens, excluding untreated controls. Ten specimens were chosen from the same treatment group of 13 replicates for the subsequent field tests. The epoxy coatings were removed after the six-week post-conditioning period under ambient conditions prior to field installation.

Field Test Site

The Living Sphere Simulation Field (LSF) of the Research Institute for Sustainable Humanosphere (RISH) of Kyoto University is located in a national pine forest (mostly *Pinus thunbergii* Parl.) growing on sandy soil in Hioki-City in Kagoshima Prefecture on the south west part of Kyushu Island, Japan, close to the East China Sea. The region has a mild climate with a mean annual rainfall of 2265 mm and mean daily temperatures of 28ºC and 7ºC in July and January, respectively, with a mean annual temperature of 18ºC. Ground cover includes grass and pine needles. *Coptotermes formosanus* Shiraki and *Reticulitermes speratus* Kolbe are present at high densities in the field. Soil-inhabiting wood-rotting basidiomycetes are also very active. The field location falls within the high decay hazard zone for outdoor above-ground exposure using Scheffer's climate index of 90 (Hasegawa 2001).

Test Installation and Inspection

Each sample was placed on a concrete building block of 40 (L) x 10 (W) x 19 (H) cm^3 in size. Untreated pine feeder stakes were driven into the soil via hollows in the concrete blocks in a way that a 0.5 to 1.0 cm gap was created between the bottom face of the samples and the feeding stake's surface to facilitate entry access for termites coming from the infested soil directly to the test samples placed on top of the concrete block (Fig. 1).

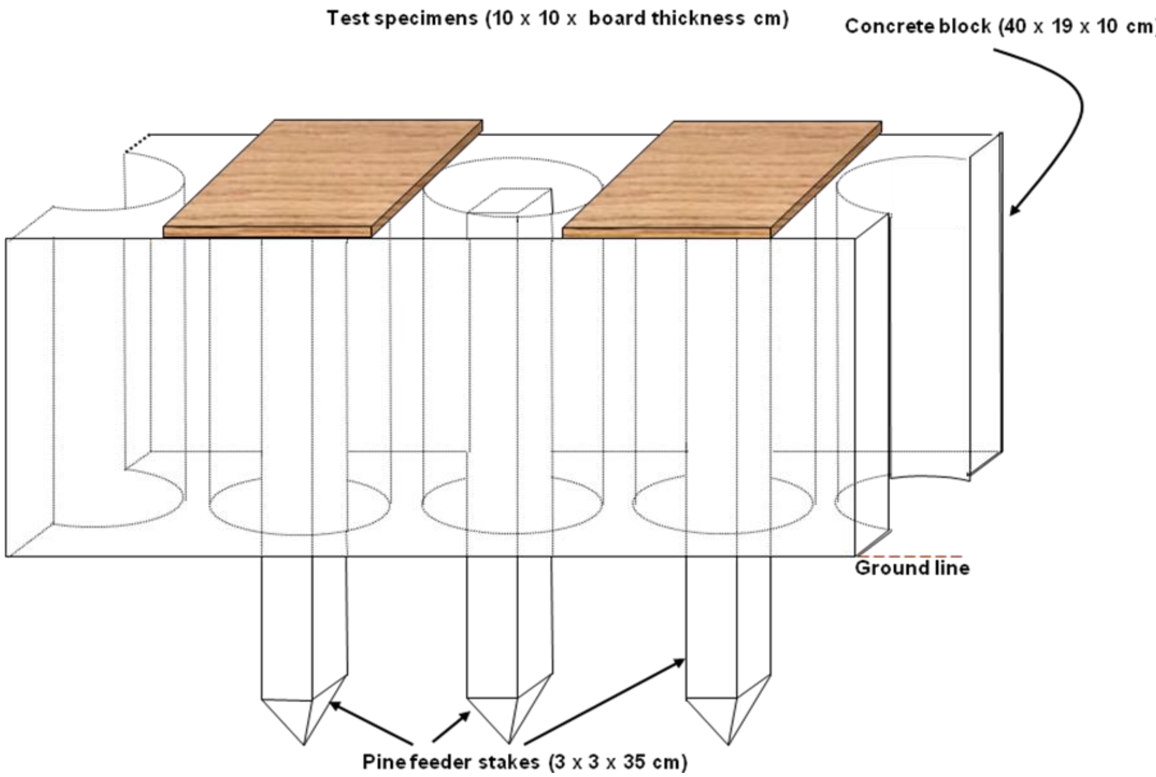

Fig. 1. Installation details of specimens and feeder stakes

A total of 250 specimens (ten replicates for each treatment and controls) were randomly assigned to 13 boxes. Sample sets on blocks were covered with inverted PVC boxes. The specimens were installed on 8 May 2009 and inspected biannually around October and April. The ten-year trial will be terminated in 2019. Samples were gently removed from the concrete blocks and inspected visually. In addition, the underside where the termites had contacted the specimen surface was probed. The samples were rated according to the American Wood Preservers' Association standard AWPA E7 (2010) on a scale of 10 to 0 for both termite attack and decay. The AWPA rating system for decay and termite consists of a damage rating scale between 10 and 0. The scale for decay is as follows: 10 (sound, suspicion of decay permitted), 9 (trace decay to 3% of cross section), 8 (decay from 3 to 10% of cross section), 7 (decay from 10 to 30% of cross section), 6 (decay from 30 to 50% of cross section), 4 (decay from 50 to 75% cross section), and 0 (failure, disintegration of sample). For termite activity the scale is as follows: 10 (sound, no signs of termite attack or decay), 9 (trace to slight attack, surface nibbling or shallow erosion), 7 (moderate attack, obvious penetration), 4 (heavy attack, deep penetration), and 0 (failure, disintegration of sample).

RESULTS AND DISCUSSION

Retentions

Mean retentions calculated based on mass differences of the wood-based composites before and after treatments are given in Table 2.

Table 2. ACQ and CA Retentions (kg/m^3) in the Post-treated Wood-based Composites as Determined by Solution Uptake

Target retention (kg/m^3)	Wood-based composites				
	SWP	HWP	MDF	OSB	PB
ACQ 2.60	3.26 (0.19)	2.05 (0.50)	2.85 (0.07)	2.45 (0.60)	2.58 (0.15)
ACQ 5.20	6.24 (0.50)	6.88 (1.45)	5.76 (0.10)	5.49 (0.97)	4.58 (0.68)
CA 1.00	0.98 (0.05)	1.23 (0.29)	1.00 (0.01)	0.91 (0.29)	1.08 (0.04)
CA 2.00	1.96 (0.18)	2.02 (0.24)	1.97 (0.04)	1.92 (0.58)	2.18 (0.04)

*****mean of 10 replicates, numbers in parenthesis are standard deviations

The results clearly demonstrate that the treatment schedules used successfully delivered both waterborne preservatives into the wood-based composites at intended retention levels with few minor variations in SWP and HWP.

Progress in Decay and Termite Attack

In general, the treated composites outperformed the untreated specimens with the exception of MDF and PB. While termite attack started in the first year on all types of untreated composites, incipient decay symptoms were not detected in the same period. The first signs of decay were recorded on SWP, HWP, and OSB after 24 months of exposure. The severity of termite attack was always higher than decay for any specimen regardless of composite type. This could be credited to the reduction of decay risk under the protected design of crawlspace conditions (Tsunoda 2008). The most resistant composite to both decay and termite activity was MDF (mean decay rating of 10 and mean termite rating of 9.3) after 3 years of exposure. PB was ranked second with no signs of decay and an 8.5 mean termite rating at the end of the same exposure time. The least resistant composites were OSB, HWP, and SWP with 5.4, 5.5, and 7.5 mean termite ratings, respectively. Their respective mean decay ratings were 9.3, 9.7, and 9.4.

Figure 2 indicates the progress in decay and termite attack on untreated and treated SWP. After 36 months of exposure, while the mean termite rating was as low as 7.5 for the untreated specimens, the ACQ-treated and CA-treated SWP specimens were rated between 9 and 9.4, indicating statistically significant improvement ($p = 0.000$) due to chemical treatment. A mean decay rating of 9.4 was recorded only for the untreated SWP, while the ACQ-treated and CA-treated SWP were free from any decay activity at the end of the exposure period. Statistical analysis (ANOVA), however, did not reveal any significant differences between preservative types and/or retention levels and termite ratings ($p = 0.465$).

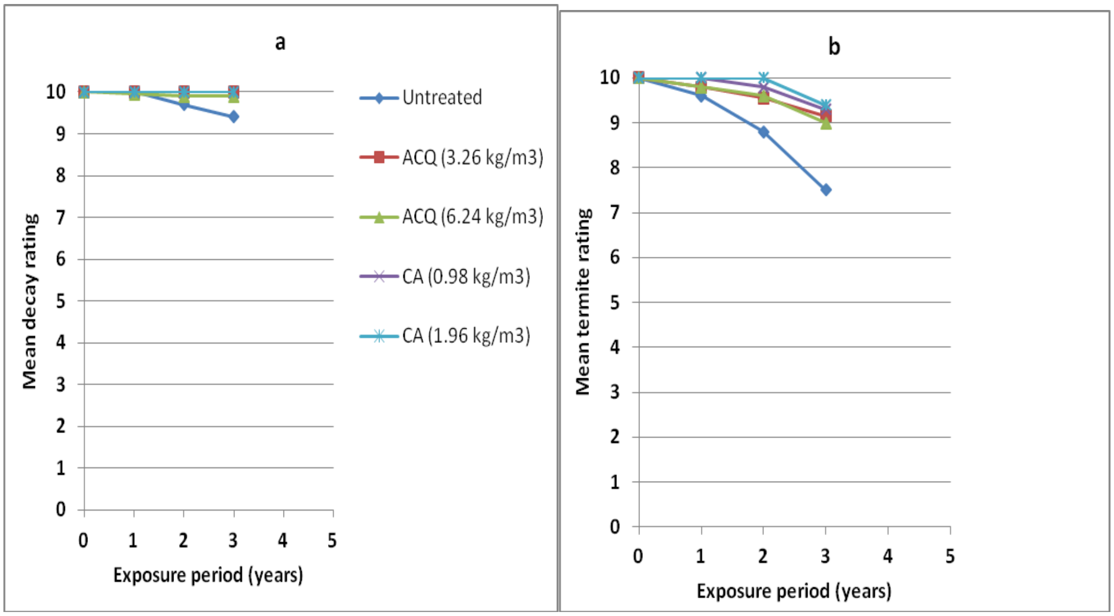

Fig. 2. Progress in decay (a) and termite attack (b) on untreated, ACQ-treated, and CA-treated SWP during 36 months of field exposure

Similarly, the ACQ and CA treatments were rated between 7.8 and 8.1 for mean termite attack, while the mean termite rating for untreated HWP was 5.5 at the end of the third year, indicating that chemical treatments significantly suppress termite activity ($p = 0.010$). Some minor signs of decay were recorded only on the untreated specimens after 2 years of exposure (Fig. 3).

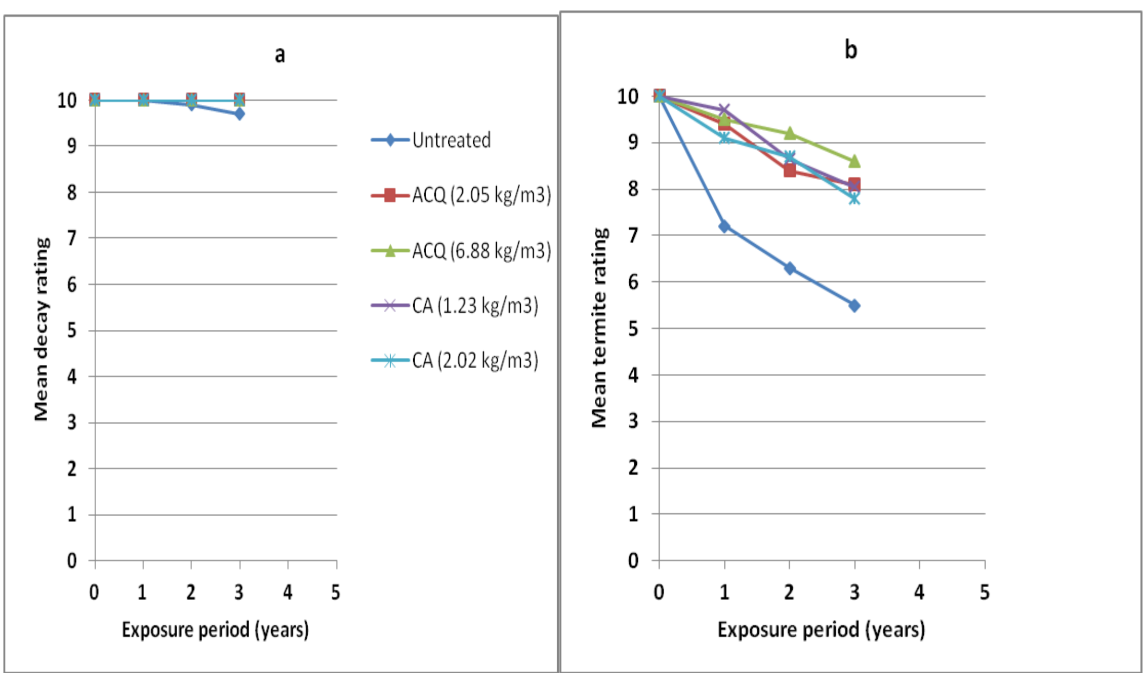

Fig. 3. Progress in decay (a) and termite attack (b) on untreated, ACQ-treated, and CA-treated HWP during 36 months of field exposure

Current preservatives and retention levels did not exhibit any statistically significant differences on termite ratings at a 0.99 confidence level (p = 0.784). The current failure modes of SWP and HWP are thought to be related by a sharp biocidal gradient between surface and core sections, with ratios (surface-to-core) ranging from 1.05 to 3.72 for ACQ and from 1.13 to 2.00 for CA (Tascioglu and Tsunoda 2012). Such a distribution gradient is believed to be responsible for leaving core sections more susceptible to biological activity. In addition, impermeable gluelines could prevent adequate preservative penetration into core veneers (Van Acker and Stevens 1989). Untreated and/or treated MDF specimens display the highest resistance with mean 10 and 9.35 ratings for decay and termite, respectively (Fig. 4).

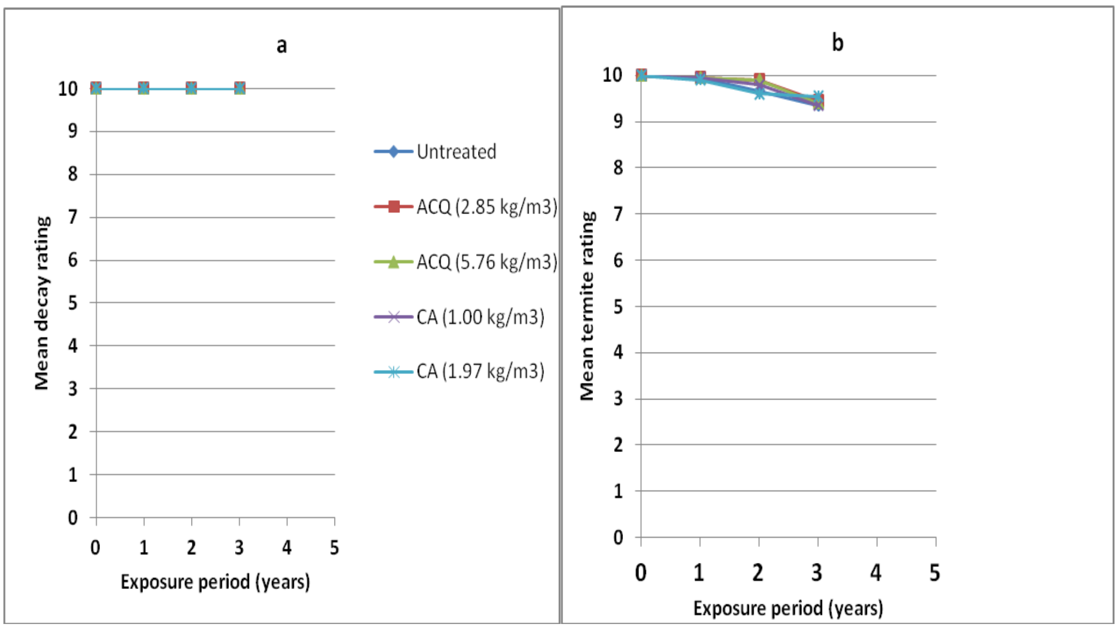

Fig. 4. Progress in decay (a) and termite attack (b) on untreated, ACQ-treated, and CA-treated MDF during 36 months of field exposure

The field test findings are in line with previous laboratory data indicating MDF's high resistance. The findings also showed that MDF requires no or minimal preservative treatment under protected above-ground applications with possible occasional wetting, assuming no changes in decay and termite ratings during the remaining period of the field test (7 more years) (Tascioglu and Tsunoda 2010a, b). This natural resistance could be attributed to their components (raw materials, adhesive types, *etc.*) and relatively high densities (Behr 1972; Okoro *et al.* 1984; Evans *et al.* 1997; Kartal and Green 2003).

OSB specimens showed the lowest resistance to decay and termite attack under field test conditions. This finding was also supported by a previous study indicating that retentions up to 2.59 and 1.01 kg/m^3 for ACQ and CA, respectively, failed to protect OSB during laboratory decay and termite tests (Tascioglu and Tsunoda 2010 a, b). For untreated OSB, the mean decay and termite rating at the end of the exposure period were 9.3 and 5.4, respectively. ACQ-treated and CA-treated OSB specimens retained mean termite ratings between 8.8 and 9.1 (Fig. 5).

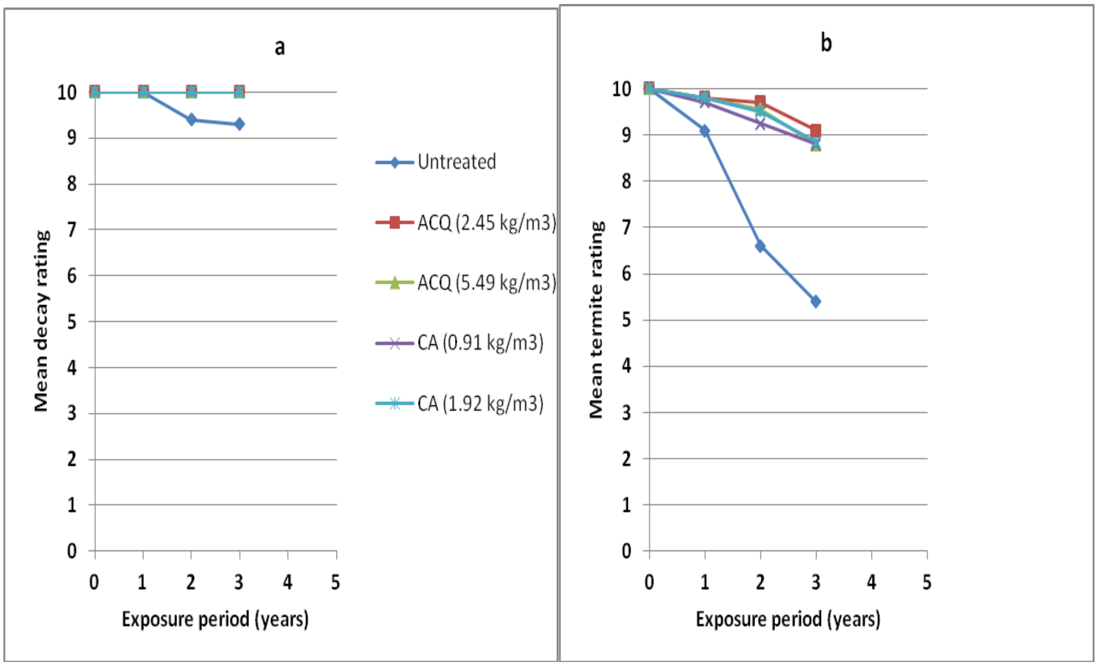

Fig. 5. Progress in decay (a) and termite attack (b) on untreated, ACQ-treated, and CA-treated OSB during 36 months of field exposure

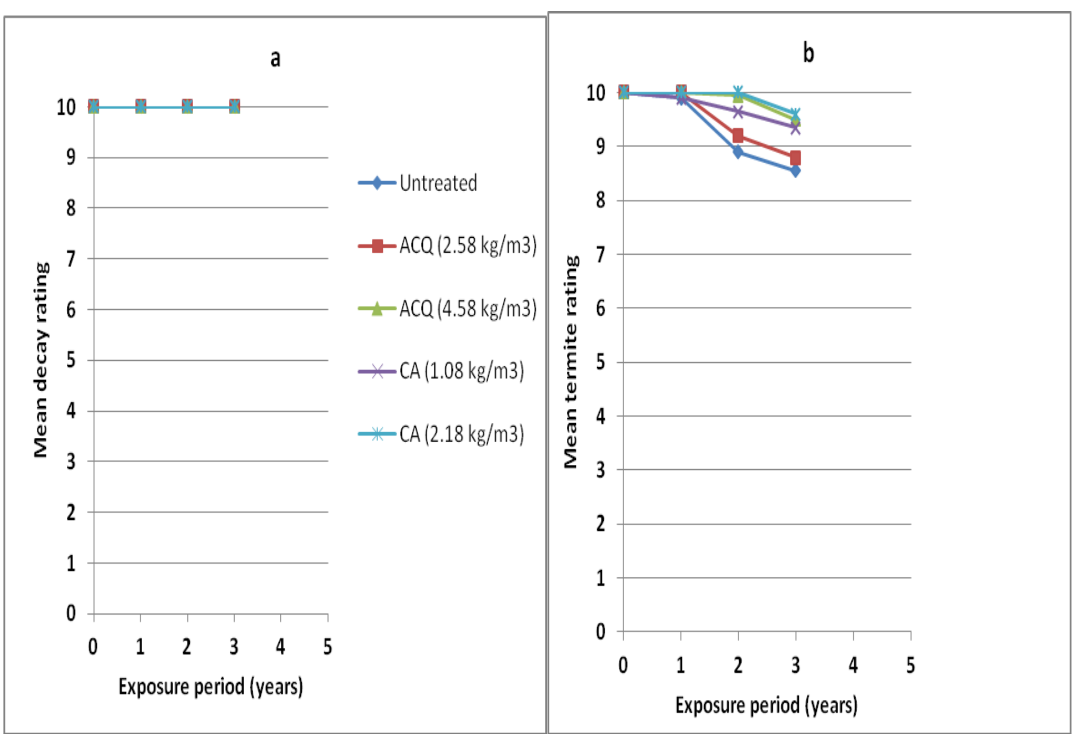

Fig. 6. Progress in decay (a) and termite attack (b) on untreated, ACQ-treated, and CA-treated PB during 36 months of field exposure

No signs of decay have been detected so far on post-treated OSB specimens, but untreated controls were rated with a mean of 9.4 for decay assessment. The tested retentions contributed significantly to the resistance of OSB against termite attack ($p = 0.000$). Although previously reported detailed chemical analyses indicated that, in most cases, a greater amount of preservative was present in core sections with surface-to-core ratios in the range 0.54 to 0.92 for ACQ and 0.63 to 0.66 for CA (Tascioglu and Tsunoda 2012), even such high retentions (5.2 kg/m^3 for ACQ and 2 kg/m^3 for CA) were ineffective to fully protect OSB specimens against *C. formosanus* and *R. speratus* activity in southern Japan. Statistical analysis (ANOVA) showed that increased retentions in both preservative chemicals did not significantly affect the durability of post-treated OSB ($p = 0.769$).

PB was rated second in terms of resistance to decay and termite attack in the field conditions. Both untreated and treated PB specimens were free from any decay signs with mean decay ratings of 10. Mean termite attack, on the other hand, was evaluated as 8.55 for untreated controls and between 8.8 and 9.6 for ACQ and CA treatments, respectively, indicating significant enhancement of antitermitic properties ($p = 0.005$) (Fig. 6).

Preservative types and/or retention levels were found to be statistically insignificant for mean termite ratings ($p = 0.036$). The relatively high decay and termite resistance of untreated PB is correlated to higher density, natural durability of the raw material, and biological resistance of the adhesive used (Kamdem and Sean 1994; Laks and Manning 1994).

CONCLUSIONS

1. The current results indicate that wood-based composites are not durable enough, even in protected above-ground conditions, if they are used without protective treatment, with the exception of MDF. MDF displayed high natural decay and termite resistance and might be used under less hazardous conditions based on three-year exposure data.
2. Post-treatment with ACQ and CA at the retention levels tested (2.60 and 5.20 kg/m^3 for ACQ, and 1.0 and 2.00 kg/m^3 for CA) significantly enhanced the termite resistance of SWP, HWP, OSB, and PB compared to their untreated controls if used in protected above-ground conditions.
3. None of the preservatives or retention levels tested was successful in providing full protection (rating 10) of wood-based composites at the end of 36 months under southern Japan field test conditions. Further investigations are needed towards the end of the planned ten-year exposure period to make conclusions on the biological resistance of post-treated composites under protected above-ground conditions.

ACKNOWLEDGMENTS

The first author extends his appreciation to Japan Society for the Promotion of Science (JSPS) for supporting this study through a post-doctoral fellowship grant (P07171) and to the late Dr. Kunio Tsunoda for initiation of the project. The authors also thank Mr. Akio Adachi for his assistance with the fieldwork.

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Article submitted: September 20, 2012; Peer review completed: November 1, 2012; Revised version received and accepted: December 17, 2012; Published: December 20, 2012.