# Durability Ratings of Post-treated Wood-based Composites after 14 Years of Field Exposure

Cihat Tascioglu,[a,]* Tsuyoshi Yoshimura,[b,]† and Wakako Ohmura [b]

Several commercial wood-based composites (softwood plywood [SWP], hardwood plywood [HWP], medium-density fiberboard [MDF], oriented strand board [OSB], and particleboard) [PB]) were post-treated with alkaline copper quat and copper azole at two different retention levels. The treated specimens were installed on concrete blocks covered with 5-sided PVC boxes simulating the crawl space conditions (protected above-ground) in Japanese houses in Southern Japan where decay and termite activity are high. The experimental variables are a comparison of treated *versus* untreated, preservative type and retention levels. During 14 years of exposure, the specimens were biannually visually rated. In general, termite damage became visible earlier and the harshness of attack was higher when compared to decay damage. The untreated and treated MDFs were the most resistant under the protected above ground conditions at the end of 14 years exposure. Particleboard durability performance followed the MDF rating during the same period. The untreated OSB, HWP, and SWP were the least resistant composite types. The treatments substantially increased the durability of the mentioned composite types by 317.6%, 80.5%, and 133% higher termite grading when correlated to their untreated controls, respectfully, yet they failed to maintain full protection. Based on statistical analysis, preservative types and retention levels did not significantly affect decay and termite ratings.

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*Contact information: a: Department of Forest Products Engineering, Faculty of Forestry, Duzce University, Duzce, 81620, Turkey; b: Research Institute for Sustainable Humanosphere (RISH), Kyoto University, Gokasho, Uji, 611-0011, Kyoto, Japan;*
** Corresponding author: cihattascioglu@duzce.edu.tr; cihattascioglu@yahoo.com*
*† Deceased author*

## INTRODUCTION

Utilization of wood-based composites (WBC) has increased over the past few decades because of their role of replacing solid wood in the construction industry. While their initial use is mostly in non-structural applications, recently structural applications are also on the rise. Because the dominant fragment is solid wood, they are prone to fungal decay and insect damage when used in outdoor conditions without treatment (Laks *et al*. 2002; Larkin and Laks 2008; Morris *et al*. 2016). Untreated softwood plywood (SWP), particleboard (PB), and oriented strand board (OSB) experienced major failures due to termite attack at the end of 5 years in Southern Japan (Tsunoda 2008). Thus, such composites demand protection against biodeterioration using various methods. The post-treatment method, treating WBCs after they are manufactured, is considered one of the protection methods. Each method has its pros and cons on the final product, ranging from changes from mechanical properties or manufacturing processes to biocide distribution on the cross sections. The post treatment method *via* brushing, dipping, or vacuum-pressure treatment is considered the most practical one because it does not interfere with the manufacturing of WBCs. The wood preservatives copper azole (CA) and alkaline copper quat (ACQ) are considered as environmentally greener alternatives in comparison to chromated copper arsenate (CCA) in this study, as they do not contain harmful arsenic and chromium elements.

The main objective of this study was to collect long-term durability data of wood-based composites post-treated with ACQ and CA in field test conditions located in Southern Japan.

## EXPERIMENTAL

### Wood-based Composites

The specific characteristics of WBCs are given in Table 1. The specimen size used was 100 mm × 100 mm × thickness of the commercially available wood-based composites. The cut ends of specimens were coated with a two-component epoxy resin to mimic a full-size composite product. Before preservative treatments, all specimens were conditioned at 60 ± 2 °C for 72 h.

**Table 1.** Fabrication Specifics of Wood-based Composites Tested

| Composite | Raw Material | Density (g/cm$^3$) | Thickness (mm) | Layer Orientation |
|---|---|---|---|---|
| SWP | *Larix* spp. | 0.59 | 12.1 | 0°/90°, 5 plies |
| HWP | Dipterocarpaceae | 0.50 | 11.7 | 0°/90°, 5 plies |
| MDF | Hardwood fibers | 0.71 | 12.0 | Random, 3 layered |
| OSB | Aspen | 0.63 | 12.7 | Random, 3 layered |
| PB | Hard/Softwood mix | 0.71 | 11.9 | Random, 3 layered |

### Wood Preservatives and Treatments

Two types of wood preservatives, alkaline copper quaternary (ACQ, Koshii Preserving Co., Ltd. Osaka, Japan) and copper azole (CA, Xyence, Gunma Japan), were used for post-treatments of wood-based composites. The target retentions were selected based on Japanese Agricultural Standard JAS 1083 (2007) as K3 and double K3, indicating 2.6 and 5.2 kg/m$^3$ for ACQ and 1.00 and 2.00 for CA. Previous laboratory decay and termite tests suggested (Tascioglu and Tsunoda 2010a,b) that to improve biological resistance, higher retentions (such as double K3) need to be tested. A series of treatments with water were performed earlier to determine average solution uptake of each the wood-based composite type because the permeability and density profiles of the composites varied notably.

Treatments were performed as vacuum impregnation at ambient temperature in a cylindrical glass container. An absolute pressure of 6 kPa was applied in the absence of treatment solution. The solution was then introduced into the cylindrical glass container containing the specimens under vacuum. The treatment durations and solution concentrations were adapted based on permeability of the composite to reach the target retentions. The treatment schedules are given in Table 2.

**Table 2.** Treatment Schedules Used

| Composite | Dry Vacuum (min) | Wet Vacuum (min) | Water Uptake ($kg/m^3$) |
|---|---|---|---|
| SWP | 30 | 60 | 153 |
| HWP | 30 | 20 | 193 |
| MDF | 10 | 1 | 398 |
| OSB | 10 | 1 | 339 |
| PB | 10 | 1 | 364 |

For each composite type and retention level, 13 specimens were treated at one charge. A total of 260 specimens were treated with performing 20 charges excluding untreated controls. Ten specimens were selected from each treatment group of 13 replicates for consequent field testing. A six week post-conditioning period was applied. The epoxy coatings were removed prior to installation in field conditions.

## Test Site Installation and Inspection

The field test site, the living sphere simulation field (LSF), is located in Hioki City in Kagoshima Prefecture, Japan. The site is a national pine forest (mostly *Pinus thunbergii* Parl.) growing on sandy soil covered with grass and pine needles. The location has a mild climate with a 2265 mm mean annual rainfall and 18 °C mean annual temperature. The field location is considered as high decay zone with a 90-climate index based on the Sheffer's climate index ratings (Hasegawa 2001).

Each specimen was randomly positioned on a concrete block of 40(L) × 10(W) × 19(H) cm in size. Beneath each specimen an untreated pine feeder stake was driven into soil through hollows in the concrete blocks. A small gap of 0.5 to 1.0 cm was generated between the feeder strips in the upper cross-section and the specimen's bottom face to facilitate entry access for termites coming from the infested soil.

A total of 250 specimens were allocated into 13 sets of concrete blocks. Each set was covered with a 5-sided PVC box. The specimens were first installed on 8$^{th}$ May 2009 and inspected visually twice a year around October and April. The test was terminated on 18$^{th}$ May 2023, marking 14 years (168 months) of exposure. The inspection details were given in a previous publication on preliminary findings (Tascioglu *et al*. 2013). Table 3 shows temperature and relative humidity (RH) variations during the years 2013 to 2016 in the field site location. Such temperatures and RHs created relatively higher equilibrium moisture contents (EMCs) calculated for WBCs in the covered exposure boxes, indicating high decay and termite hazard. This high risk is also supported with the Sheffer's climate index of 90 for the field test area.

## Calculation of Combined Mass Loss

All WBC specimens were conditioned at 60 °C in an oven for 72 hours before installation to the test site. At the end of the 14 years test period, all specimens were brought back to laboratory in Uji, Kyoto. Before measuring the specimen's post exposure mass, the damaged specimens were carefully brushed with a soft brush to clean their surfaces from excess debris. After air drying, the specimen surfaces were brushed with a soft brush once more to remove minor debris, paying maximum attention to avoid further wood mass loss. The specimens were re-conditioned at 60 °C for 72 h and weighed to calculate mass loss. The calculated mass reflects the total mass loss caused by decay and termite activity combined.

**Table 3**. Average Monthly Temperatures (*T*, °C) and Relative Humidities (RH, %) of Kagoshima Field Test Area Measured by a local HOBO® Meteorological Station between November 2013 and April 2016

| | | First 6 months | | | | | | Second 6 months | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Jan.** | **Feb.** | **March** | **April** | **May** | **June** | **July** | **Aug.** | **Sept.** | **Oct.** | **Nov.** | **Dec.** |
| **2013** | T | | | | | | | | | | | 8.3 | 7.3 |
| | RH | | | | | | | | | | | 88.7 | 80.4 |
| | EMC | | | | | | | | | | | 20.2 | 16.6 |
| **2014** | T | 8.9 | 10.6 | 14.9 | 17.7 | 21 | 23.1 | 27.1 | 26.2 | 22.9 | 19.5 | 14.2 | 7.1 |
| | RH | 88.1 | 82.8 | 85.0 | 85.9 | 90.2 | 96.1 | 84.6 | * | * | * | 72 | 80.8 |
| | EMC | 19.9 | 17.4 | 18.2 | 18.5 | 20.6 | 24.7 | 17.5 | * | * | * | 13.8 | 16.7 |
| **2015** | T | 8.9 | 10.9 | 16.9 | 18.8 | 21.0 | 23.4 | 26.9 | 25.3 | 22.4 | 17.9 | 18.9 | 10.4 |
| | RH | 80.2 | 82.7 | 88.2 | 90.0 | 94.1 | 97.3 | 91.9 | 94.5 | 90.6 | 84.2 | 94.0 | 87.6 |
| | EMC | 16.5 | 17.4 | 19.7 | 20.6 | 23.2 | 25.8 | 21.3 | 23.3 | 20.7 | 17.8 | 23.2 | 19.6 |
| **2016** | T | 7.1 | 9.7 | 12.5 | 17.2 | | | | | | | | |
| | RH | 87.3 | 82.7 | 85.0 | 90.8 | | | | | | | | |
| | EMC | 19.5 | 17.4 | 18.3 | 21.1 | | | | | | | | |

* Indicates missing data due to temporary malfunction of RH sensor;
** The Equilibrium Moisture Contents (EMC) were calculated based on the HOBO data.

## RESULTS AND DISCUSSION

### Preservative Retentions

Table 4 suggests average retentions of treated WBCs based on mass differences of composites before and after the treatments. In general, the applied treatment schedules successfully delivered both preservatives into the WBCs at targeted retention levels with few minor deviations in SWP and HWP samples.

**Table 4.** ACQ and CA Retentions in Post-Treated Wood-Based Composites (kg/m$^3$)

| Target Retentions (kg/m$^3$) | 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) |

* The values are average of 10 replicates numbers in parenthesis are standard variations

### Decay and Termite Ratings

When the decay ratings are considered, the treated SWPs outperformed the untreated SWP controls (Fig. 1). The termite ratings indicated that the preservative treatments significantly improved termite resistances of SWP, HWP, and PB with p-values of 0.000, 0.000, and 0.025, respectively. The first signs of decay started after 24 months of exposure for SWP and HWP, while PB and MDF demonstrated the first decay signs after 54 and 84 months of exposure, respectively. The earliest decay sign was on untreated OSB after 18 months and for the treated OSB after 42 months, as shown in Fig. 4. Overall, the first termite activity signs were recorded much earlier than decay signs for all composite types with the exception of MDF.

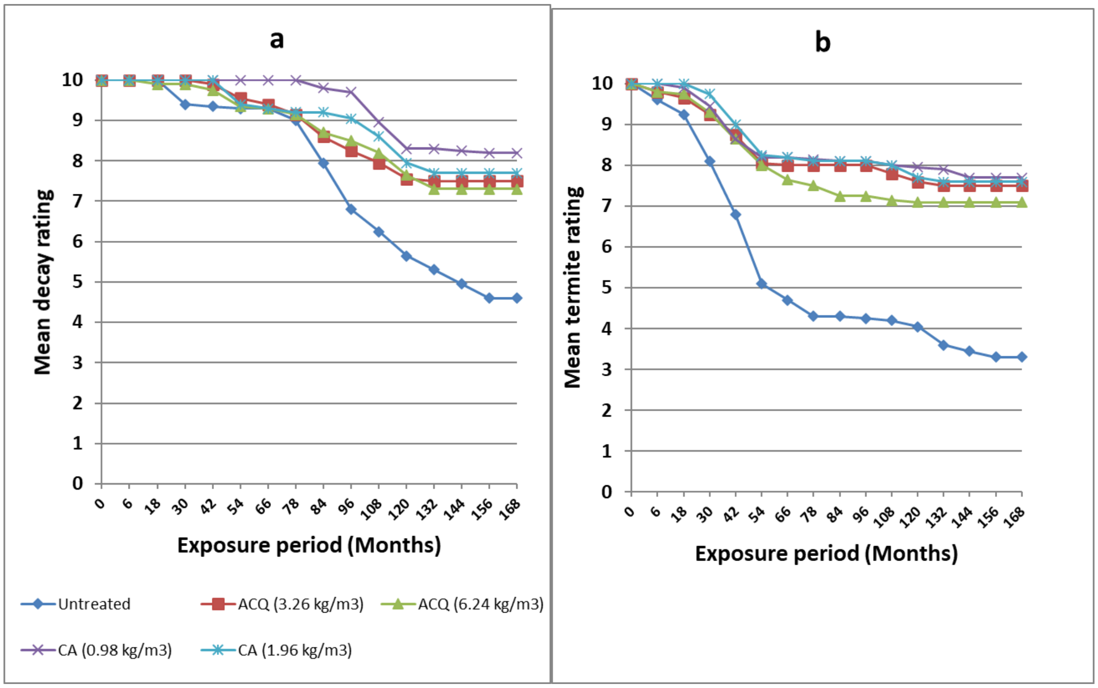


**Fig. 1.** Mean decay (a) and termite (b) rating changes of untreated, ACQ- and CA-treated SWP during 14 years of field exposure (n = 10 for each group)

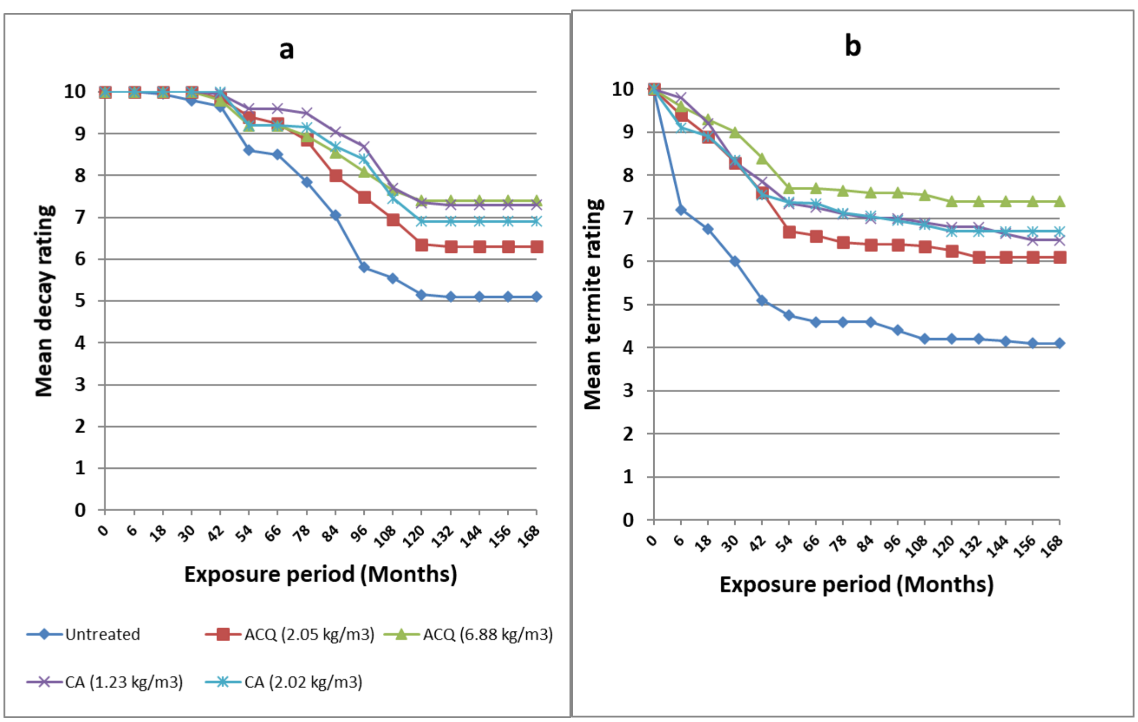


**Fig. 2.** Mean decay (a) and termite (b) rating changes of untreated, ACQ-treated, and CA-treated HWP during 14 years of field exposure (n = 10 for each group)

Untreated SWP, HWP, and OSB exhibited termite decay signs as early as 6 months of exposure. This period was 18 months for untreated and treated MDF. Additionally, the severity of termite attack was always higher than decay damage for all composite types except for HWP. This might be explained by the reduced decay risk of protected above-ground exposure conditions (crawlspace *vs*. open field), as mentioned in a previous study (Tsunoda 2008). Figure 1 indicates progress in decay and termite attack on untreated and treated SWP. Mean decay and termite ratings of untreated SWP were recorded as 4.6 and 3.3, respectively, at the end of 14-year exposure period, while post-treated SWP ratings were between 7.3 and 8.2 for decay and 7.1 and 7.7, suggesting statistically significant improvements for decay ($p = 0.016$) and for termite (0.000) resistances due to ACQ and CA treatments. However, a statistical analysis of variance (ANOVA), did not affirm any significant differences among preservative types and/or retention levels for decay ($p = 0.285$) and termite ($p = 0.469$) ratings.

Similar results were found for untreated and post-treated HWP only in termite ratings. Figure 2 shows that the mean termite rating was reduced to 4 for untreated HWP, whilst ACQ- and CA-treated specimens were evaluated between 6.1 and 7.4 at the end of the same exposure period. The preservative treatments assisted to improve termite rating of HWP when compared to the untreated controls ($p = 0.000$). The decay ratings were concluded as insignificant at the 0.99 confidence level when untreated and treated HWP were correlated ($p = 0.113$). Once more, no significant differences were observed amongst preservative types and/or retention levels ($p = 0.285$). The reported failures in SWP and HWP could be attributed to uneven biocidal distribution within the cross-sections of the treated composites. On a previous study, the surface to core ratios were described as from 1.05 to 3.72 for ACQ and from 1.13 to 2.00 for CA (Tascioglu and Tsunoda 2012), leaving core sections prone to decay and termite activity.

**Fig. 3.** Edgewise failure details on SWP and HWP specimens; While the surface veneers look intact, most damage was initiated from edges and progressed *via* core veneers where the retention of biocide was low.

The long-term filed data revealed that among all the WBCs tested, the MDF demonstrated the highest resistance to decay by fungi and termite activity with or without biocide (Fig. 4). The lowest decay rating was reported as 8.6 for untreated controls, suggesting only 14% reduction after 14 years of exposure in Kagoshima. Furthermore, the termite resistance was recorded as relatively high when compared to the other composites tested. The termite ratings were reduced from 10 to 7.8 for untreated controls, a 22% reduction, at the end of the same period. The preliminary report indicated that the MDF specimens produced no decay signs and limited termite damage after 36 months of exposure due to the presence of other components (raw materials, adhesive types, higher density, and chemical differentiation). This situation was changed by years, and further damage was observed and accumulated during the late stages of the exposure period. When all treatment ratings were compared for decay and termite activity, no statistically significant results were found ($p = 0.876$ for decay and $p = 0.885$ for termite activity), implying the wood preservative chemicals and retention levels did not contribute to the durability of the MDF tested.

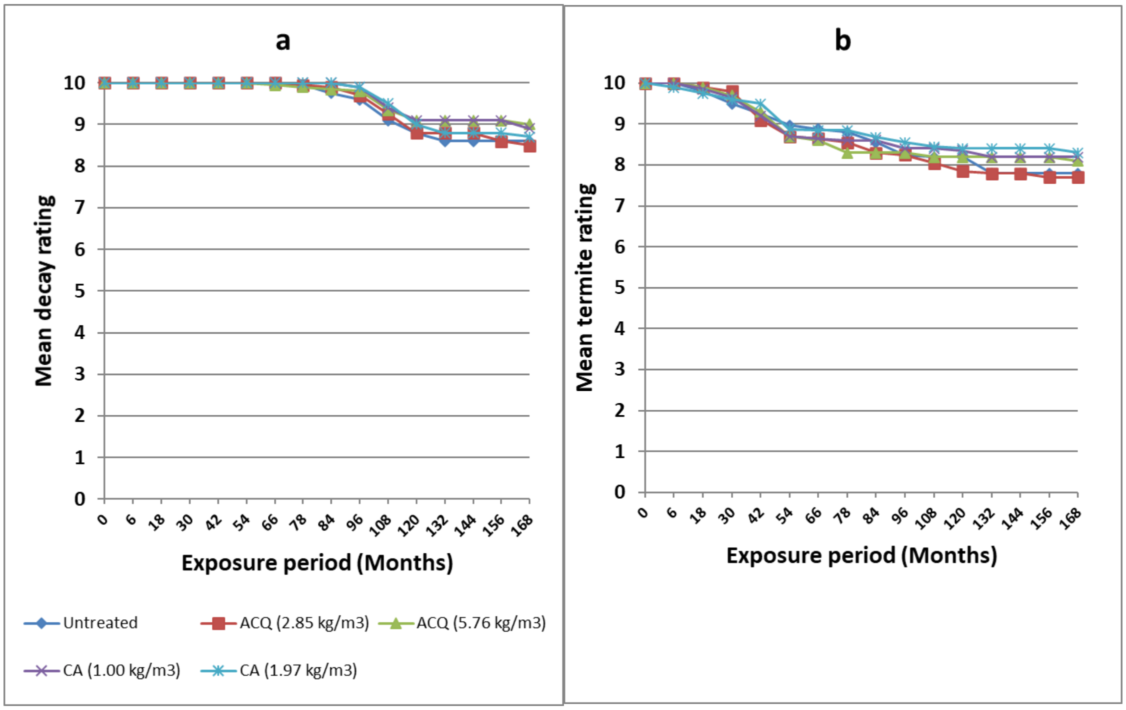


**Fig. 4.** Mean decay (a) and termite (b) rating changes of untreated, ACQ- and CA-treated MDF during 14 years of field exposure (n = 10 for each group)

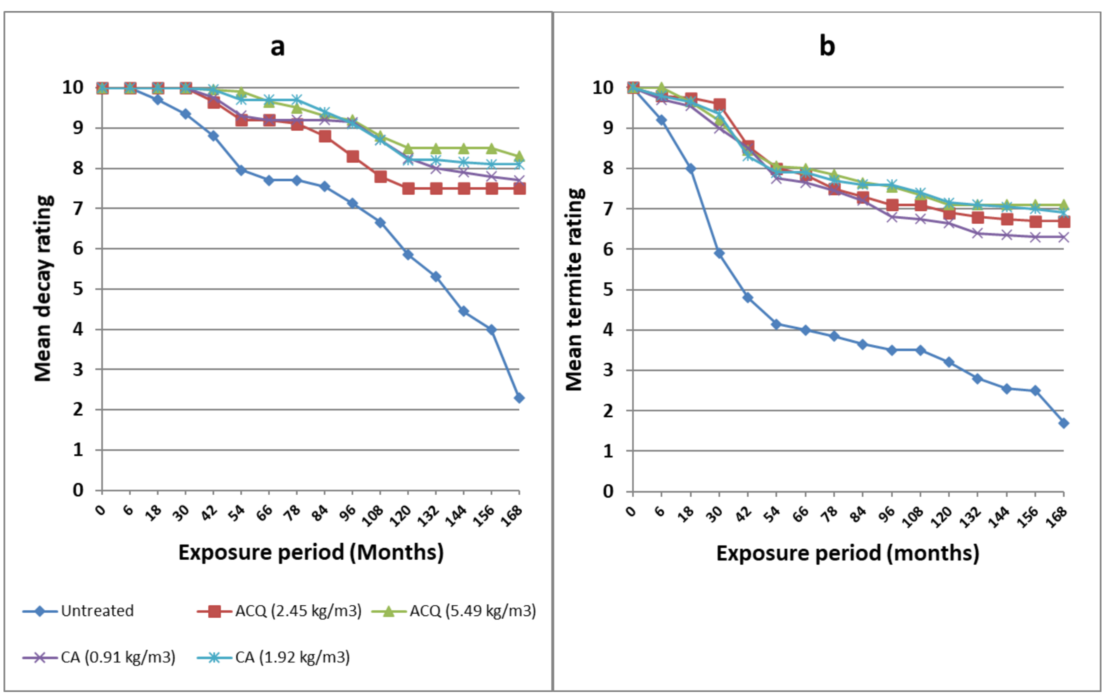


**Fig. 5.** Mean decay (a) and termite (b) rating changes of untreated, ACQ- and CA-treated OSB during 14 years of field exposure (n = 10 for each group)

The OSB specimens displayed the lowest resistance to decay and termite attack during the same period. The mean decay and termite ratings were decreased to 2.3 and 1.7, respectively, almost losing their integrity (Fig. 5). In contrast, ACQ and CA treatments notably increased decay and termite resistances of OSB specimens, upholding mean decay ratings between 7.5 and 8.1 and mean termite ratings between 6.3 and 7.1 after 14 years of exposure. Even the highest retentions were ineffective to fully protect OSB specimens under Kagoshima's high decay and termite risk environment. Again, no statistical differences were determined amongst preservative types and retentions for decay and termite exposures with 0.288 and 0.363 p-values respectively.

The signs of decay became visible after 42 months of exposure on the treated OSB, while the untreated OSB showed decay signs as early as 18 months (Fig. 5). When termite activity was concerned, the first signs were observed much earlier, as 6 months and 18 months for untreated and treated OSBs, respectively. According to a previous report, although the greater amount of biocide was detained in core sections of the OSBs, even the highest retentions were inadequate to fully protect OSB specimens against termite pressure in Southern Japan.

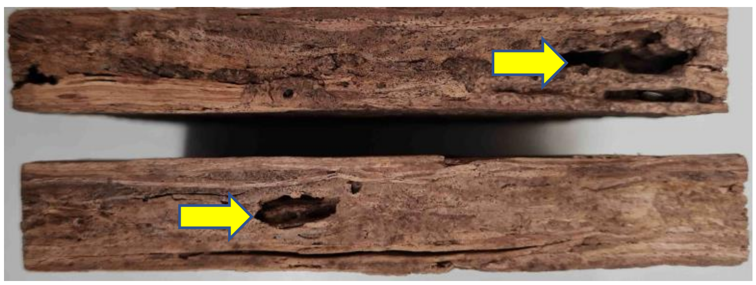

**Fig. 6.** Edgewise failure details on OSB specimens. In some cases, termite damage was initiated from edges of core sections of OSB specimens indicating full protection threshold level was not achieved even at those high retention areas.

The PB was rated as the second group of WBCs that is resistant to biological activity after MDF (Fig. 7). It is worth mentioning that ACQ and CA treatments did not contribute significantly to the decay resistances of PB samples tested, as an ANOVA analysis resulted in 0.358 p-value when all treatments were compared. At the end of the exposure period, the decay ratings were recorded between 7.2 and 8.5 for all retentions. This represents reductions in the range 15% to 28% in decay ratings after 14 years of exposure. Contrarily, termite ratings revealed that the preservative treatments supported termite resistance with mean ratings between 7.6 and 7.9 after 14 years of exposure ($p = 0.025$). At the end of the same exposure period, the untreated controls had a 6.4 mean termite rating. Preservative types and/or retentions were found statistically insignificant with a p-value of 0.576.

Morris *et al*. (2014) reported that ACQ-D pressure treated lodgepole pine solid wood specimens at 4.9 kg/m3 retention level resulted in 10 and 8.9 mean termite ratings at the end of 24 and 60 months of exposure periods, respectively. The same specimens gave much lower mean termite rating, as 9.2 and 7.7, at the end of the same exposure times in Hawaii, USA (Morris *et al*. 2014). When compared to current study at the end of the same exposure periods, the termite ratings were significantly lower regardless of composite type. This indicates that ACQ treated solid wood specimens and WBCs perform differently.

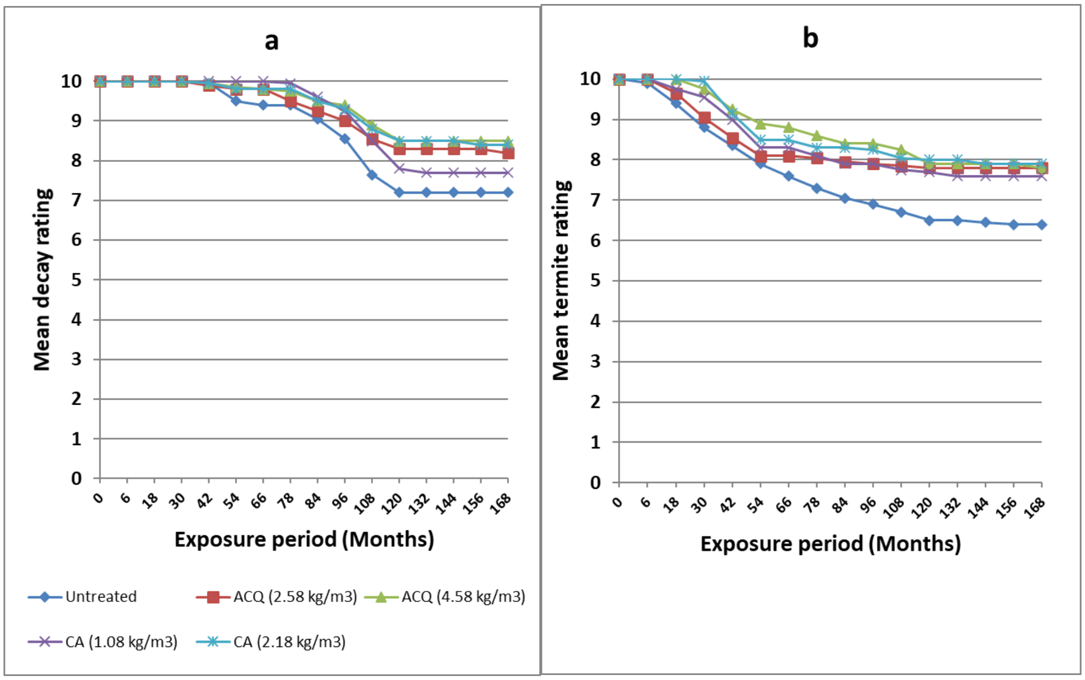


**Fig. 7.** Mean decay (a) and termite (b) rating changes of untreated, ACQ- and CA-treated PB during 14 years of field exposure (*n* = 10 for each group)

## Combined Mass Loss

The weight loss data was in accordance with the visual ratings. The highest combined mass loss was recorded as 71% for untreated OSB specimens. The treatments on OSB specimens helped to keep the combined mass loss below 20% (Fig. 8).

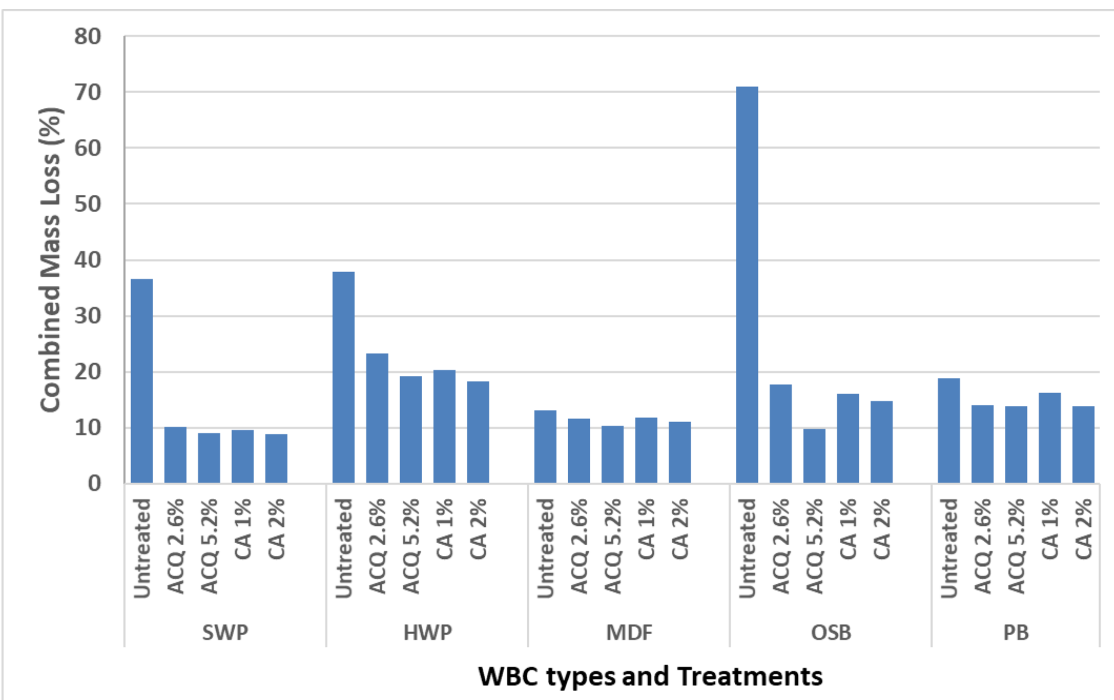


**Fig. 8.** Mean percentages of combined (decay and termite) mass losses of WBCs tested at the end of 14 years of field exposure (n = 10 for each group)

Both plywood groups showed around 36% to 37% combined mass loss for the untreated controls. For the treated specimens, however, the combined mass loss values were greatly different. While the SWP combined mass losses were less than 10%, the same treatments resulted in combined mass losses between 18% and 23% for HWP specimens, suggesting that biocide treatments notably hampered fungal and termite activities. The second lowest mass losses were listed for PB specimens between 13.8% and 18.9%. The preservative chemicals had limited effect. The lowest mass losses were displayed between 10.4% and 11.8% for treated MDF specimens. Interestingly, the untreated MDF specimens demonstrated only 13% combined mass loss, suggesting a high natural durability of MDF under protected above-ground conditions for 14 years. Due to this high natural durability tested, biocides seemed to have limited effects on MDF's increased durability.

## CONCLUSIONS

1. The results showed that all types of wood-based composites (WBC) tested were not durable enough in protected above-ground conditions in Southern Japan. Most durable among the WBCs tested without biocide was medium-density fiberboard (MDF), followed by particleboard (PB).
2. In all cases, signs of termite activity started much earlier when compared to the signs of decay attack. Similarly, the severity of termite attacks was higher than the severity of fungal attack. Fungal activity became visible in later stages of 14 years of exposure period.
3. The post treatment method with alkaline copper quat (ACQ) and copper azole (CA) significantly enhanced decay and termite resistances and reduced combined mass losses of all WBC, except for MDF and PB samples.
4. None of the preservatives and retention levels tested were successful for providing full protection after 14 years of exposure.

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