Decay, Mold, and Termite Resistance of High-density Fiberboard from Wood and Chicken Feather Fibers

Menandro N. Acda,[a,]* Mylene D. Rizare,[b] and Anne Patricia G. Cantalejo [a]

The decay, mold, and termite resistance of high-density fiberboard (HDF) formed using combinations of wood and chicken feather fibers (CFF) bonded with polyurethane resin was investigated. Laboratory and underground field exposure tests showed that HDF containing 50% to 100% CFF by weight were moderately to highly resistant to the white-rot fungus *Pycnoporus sanguineus* (L.) Murrill and the subterranean termite *Coptotermes gestroi* Wasmann. Moderate to heavy mold growth was observed on HDF containing 25% to 100% CFF when inoculated with a mixed strain of *Aspergillus niger*, *Penicillium chrysogenum*, and *Trichoderma viride*. In general, HDF consisting of wood fibers and CFF was resistant to decay and subterranean termite but susceptible to mold growth. The susceptibility HDF to mold may require the use of a biocide to improve mold resistance.

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Contact information: a: Department of Forest Products and Paper Science, University of the Philippines Los Banos, College, Laguna 4031 Philippines; b: Department of Science and Technology, Forest Products Research and Development Institute, College, Laguna 4031, Philippines;
** Corresponding author: mnacda@up.edu.ph*

INTRODUCTION

High-density fiberboard (HDF) is an engineered wood product made from wood fibers bonded together with an adhesive and consolidated under high temperature and pressure. It is harder and denser (> 800 kg m^{-3}) than the original wood from which it was made. It is widely used as a substitute for solid wood in non-load bearing applications such as door skins, laminate flooring, high grade furniture, cabinet, windows, and door frames (Stark *et al.* 2010). HDF's high dimensional stability and smooth surface make it suitable to receive various coatings (varnishes, paints, *etc.*) and ease of processing to various shapes and sizes for interior design applications (Stark *et al.* 2010). In addition, because the raw material used for HDF manufacture is mostly from waste wood chips, it is considered renewable and an environmentally friendly product.

In recent years, the problems of global warming and climate change brought about by the widespread use fossil fuels have gained worldwide public concern (Habib *et al.* 2021; Ahmed *et al.* 2022). Consequently, many countries as a matter of policy have incorporated the use of green and environmentally friendly products and technologies to achieve sustainable development goals (Faura 2022; UN 2024). An abundant material that can be used to produce HDF is chicken feather fibers. Chicken feathers are a waste product of commercial chicken dressing plants. The large amount of waste feathers produced annually creates a serious solid waste disposal problem in many countries (Tesfaye *et al.* 2017; USDA 2018; Muduli *et al.* 2019). Chicken feather is made up of a polymer called keratin that is cross-linked together to form a strong and lightweight natural fiber (Wang *et al.* 2016). This property makes chicken feather fibers tough and durable, and they also are known to be very resistant to biodegradation.

Previous studies have shown that chicken feather fiber (CFF) can be used as raw material for the manufacture of medium density fiberboard (Winandy *et al.* 2014; Safaric *et al.* 2020), biocomposites (Cheng *et al.* 2009; Ma *et al.* 2016; Aranberri *et al.* 2017; Jung *et al.* 2019), textiles, membranes (Shanmugasundarama *et al.* 2018; Ali *et al.* 2021), as a carbon source (Singh *et al.* 2018; Choudary 2019; Li *et al.* 2020), and as reinforcement in cement composites (Acda 2010). The keratin present in chicken feather is an insoluble and highly durable protein found in the hair, hoofs, and horns of animals. Keratin consists of several amino acids, but largely cystine, lysine, proline, and serine. These monomers cross-link with one another, primarily through disulfide bonds and non-covalent interactions, forming tough, strong and lightweight fibers that are very resistant to biodegradation and with good thermal and acoustic insulating properties (Fig. 1).

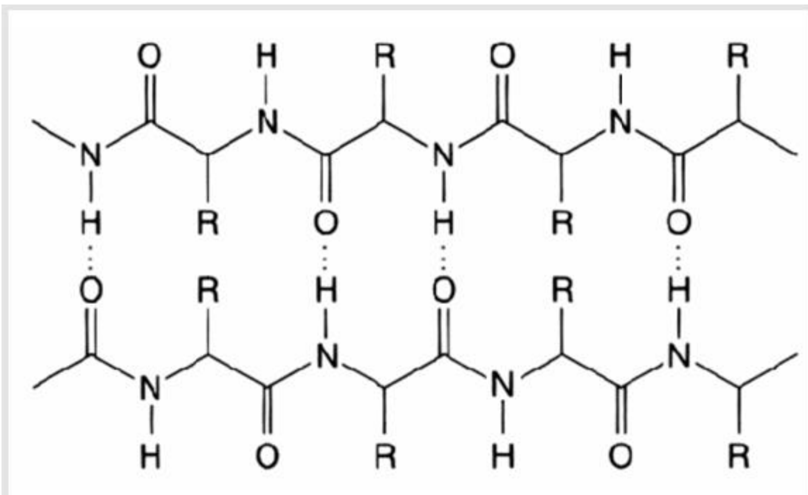

Fig. 1. Chemical structure of keratin from chicken feather

The authors' previous study showed that HDF can be produced using combinations of wood and chicken feather fibers bonded together using polyurethane resin (Acda 2022). The HDFs containing as much as 50% chicken feather fibers were dimensionally stable, with stiffness and strength above the minimum requirements of EN 622-5 (2009). Dimensional stability, as indicated by low levels of thickness swelling (< 4.6%) and water absorption (< 10%), was observed. Internal bond (2.47 MPa), modulus of elasticity (MOE) (5.8 GPa) and modulus of rupture (MOR) (45 MPa) values were higher or comparable to those reported in the literature (Acda 2022). However, experiments on durability and resistance of HDF against decay and insects were ongoing at the time and were not reported in the cited work. The present paper reports on decay, mold, and termite resistance of high-density fiberboard from wood and chicken feather fibers to evaluate their suitability as building material. The HDF is a high-volume product that can potentially utilize the significant amount of waste chicken feather from poultry processing facilities. Such utilization can help alleviate solid waste disposal problems, reduce pollution, and efficiently use an alternative renewable fiber for sustainable development.

EXPERIMENTAL

Board Formation

The details of HDF formation using wood fibers and CFF, resin, and consolidation method were described elsewhere (Acda 2022). Briefly, HDF panels measuring 6 mm x 240 mm x 240 mm were dry formed (density 985 kg m^{-3}) using various combinations of wood fibers (*Gmelina arborea* Roxb.) and CFF, *viz.*, 100/0, 75/25, 50/50, 25/75, and 0/100 by weight. Wood fibers and CFF were uniformly mixed and spray-coated while tumbling with polyurethan resin (PUR) dispersed in acetone. The amount of PUR used was 12% based on oven-dry weight of wood fibers. No wax or other additives was used in this study. The mixture was uniformly formed into a fiber mat and consolidated by pressing in a hydraulic press using 140 kg cm^{-2} and 140 °C for 4 min. The pressure was slowly released after board curing to prevent residual acetone from blowing the panels. The boards were trimmed after 24 h then conditioned for six weeks at 21 °C and 65% relative humidity prior to decay and insect testing. Five replicate boards were made for each treatment combination.

Decay Resistance

The decay resistance of HDF consisting of various ratios of wood fibers and CFF was performed following ASTM D2017-05 (2005) with some modifications. *Paraserianthes falcataria* (L.) Nielsen (Moluccan sau) sapwood was used as feeder strips in bottles inoculated with a pure culture of the white-rot fungus *Pycnoporus sanguineus* (L.) Murrill. The sapwood feeder strips were laid flat on the soil surface in each bottle. The bottles with the feeder strips were loosely capped and steam-sterilized at 121 °C for 30 min. After cooling, the feeder strips in each bottle were inoculated with *P. sanguineus*. All HDFs (6 mm x 25 mm x 25 mm) were oven-dried at 105 °C then conditioned to constant weight at 25 °C and 50% relative humidity. The HDFs were then steam-sterilized and placed on the fungus covered feeder strips in bottles inoculated with the test fungus. All bottles were incubated at 28 °C and 70% relative humidity. Four replicate specimens were used for each combination of wood and CFF fiberboard. After 12 weeks of fungal exposure, specimens were conditioned as described above and weight loss determined and expressed as a percentage of the initial weight. Specimen fungal resistance was also rated in terms of mean weight loss following the scale: 0 to 10% = highly resistant, 11 to 24% = resistant, 25 to 44% = moderately resistant, > 45% non-resistant. Data for weight loss were evaluated by analysis of variance (ANOVA) using Statgraphics Centurion 19 software (Manugistics Inc., Rockville, MD, USA). Means were separated by Tukey's Honest Significance Difference (HSD) test ($\alpha = 0.05$).

Mold Resistance

Mold susceptibility of HDF specimens was performed following ASTM D4445-10 (2010) with modifications to mold species and size of specimen. Mixed mold fungi strains from the stock culture of the Forest Products Research and Development Institute, Department of Science and Technology consisting of *Aspergillus niger* ATCC 1015, *Penicillium chrysogenum* Thom, and *Trichoderma viride* Pers were used in this study. Mold was grown on 2% malt agar Petri plates maintained at 27 °C and 80% relative humidity. Spore suspensions of mold trains were prepared from 2-week-old fungal colonies by washing the surface of the malt agar Petri dish with 10 to 15 mL of sterile distilled water. The wash water was then transferred to a spray bottle, diluted to approximately 100 mL of distilled water, and then adjusted to deliver 1 mL of inoculum per spray. The HDF specimens (40 x 60 mm^2) were added to each Petri dish (150 x 25 mm^2) containing a layer of ordinary filter paper (Grade 2) saturated with 30 mL of distilled water. A polyethylene spacer (1 x 20 x 120 mm^3) was used to elevate test specimens. Plates containing filter paper and test specimens were spray-inoculated with 1 mL mold spores and incubated at 27 °C, 70% RH for 4 weeks. Four replicates were used for each wood fiber-CFF board combination. Following incubation, specimens were assigned visual ratings for percentage of mold coverage (*i.e.*, growth/coverage rating) following the scale: 0 = no growth, 1 = 20%, 2 = 40%, 3 = 60%, 4 = 80%, and 5 = 100% coverage with mold. Mold growth was rated by three individuals and mean determined. Mean mold growth ratings were analyzed and separated by Tukey's Honest Significance Difference (HSD) tests described above.

Termite Resistance

The HDF specimens (10 mm x 38 mm) containing combinations of wood fibers and CFF were used for the laboratory no choice feeding bioassay in accordance with the JWPA 11(1)-81 (1981) standard with minor modifications to the number of termites introduced into the test container. Each sample was placed on the center of a plaster-bottomed cylinder (80 mm diameter and 60 mm height) set on damp cotton pads to keep the sample moist. *Coptotermes getroi* Wasmann (Blattodea: Rhinotermitidae) (200 workers and 20 soldiers), a destructive subterranean termite species in Southeast Asia, was added and incubated at 28 °C for 5 weeks. Five replicates were used for each wood fiber-CFF combination. At the end of the incubation period, termite mortality and percentage weight losses of the HDF specimens were determined and compared with boards containing wood fibers only.

Fig. 2. Underground subterranean termite exposure test consisting of cylindrical concrete block inside a PVC clean out tube with removable cap

The resistance of HDFs to subterranean termites was further evaluated using an underground field exposure test. One sample (25 x 100 mm^2) was placed on top of a cylindrical concrete block (60 mm diameter x 50 mm height) inside a PVC clean out tube

(110 mm diameter x 245 mm height) with cap (143 mm x 17 mm) to facilitate inspection and recovery of specimen (Fig. 2). Each tube was installed underground in three high termite hazard locations within the University of the Philippines Los Banos campus. Each location was at least 1 km apart with known active field colonies of *Macrotermes gilvus* Hagen, *Nasutitermes luzonicus* Light, *Microcerotermes losbanosensis* Oshima, and *Coptotermes gestroi* Wasmann. Five replications 5 m apart were used in each test location. All samples were exposed for a total of 16 weeks from August to November 2023. Weight losses of specimens were calculated from the difference between the weights of test specimens before and after termite exposure as described above.

RESULTS AND DISCUSSION

Decay Resistance

The decay resistance test of HDFs to the white-rot fungus *P. sanguineus* resulted in significant loss in weight (p-value < 0.001) with increasing proportion of CFF during the 12-week exposure period (Figs. 3 and 4). The HDFs specimens in this study did not inhibit the growth of *P. sanguineus*, as indicated by active mycelium on the surface of all specimens (Fig. 3). Boards containing 50 to 100% CFF (*i.e.*, 50/50 to 0/100 wood fiber/CFF ratio by weight) were resistant to highly resistant to *P. sanguineus* (10 to 20% weight loss) compared to boards containing 100% wood fibers only (*i.e.*, 100/0 ratio). CFF is naturally resistant to biodeterioration and may have contributed to its decay resistance in this study. The weight loss from HDF specimens containing a mix of wood fibers and CFF were presumed mainly from loss of wood biomass due to degradation by *P. sanguineus*. However, HDF containing 100% CFF also experienced a slight weight loss. It is unclear why this happened, since CFF is very durable and resistant to biodegradation (Poole *et al.* 2009; Wang *et al.* 2016). It is possible that the weight loss was caused by contamination of other microorganisms (fungi and bacteria) and experimental errors in our setup and procedures. Various microorganisms such as *Aspergillus*, *Acremonium*, *Alternaria*, *Beauvaria*, *Curvularia*, *Paecilomyces*, and *Penicillium* are reportedly able to break down chicken feather fibers (Marcondes *et al.* 2008).

HDFs containing 0 to 25% CFF (*i.e.*, 75/25 and 100/0 ratio) experienced a 33 to 45% weight loss, suggesting that the boards were moderate to not resistant to *P. sanguineus* in this composition. Apparently, the proportion of CFF at 75/25 and 100/0 were not sufficient to provide protection, and the use of commercial biocide may be necessary to prevent attack of decay fungi at this level (Fig. 3). Unfortunately, limited studies on decay resistance of high-density fiberboard have been reported in the literature. Consequently, it is difficult to make a comparative evaluation of its decay performance. However, the weight loss of HDF specimens observed in this study was lower compared to that obtained with medium-density fiberboard (MDF) made of wood and chicken feather fibers (Winandy *et al.* 2010). The density of HDF and wood species used in these studies are different and may have influenced the result (Kartal and Green 2003; Benthien *et al.* 2012; Arango *et al.* 2020).

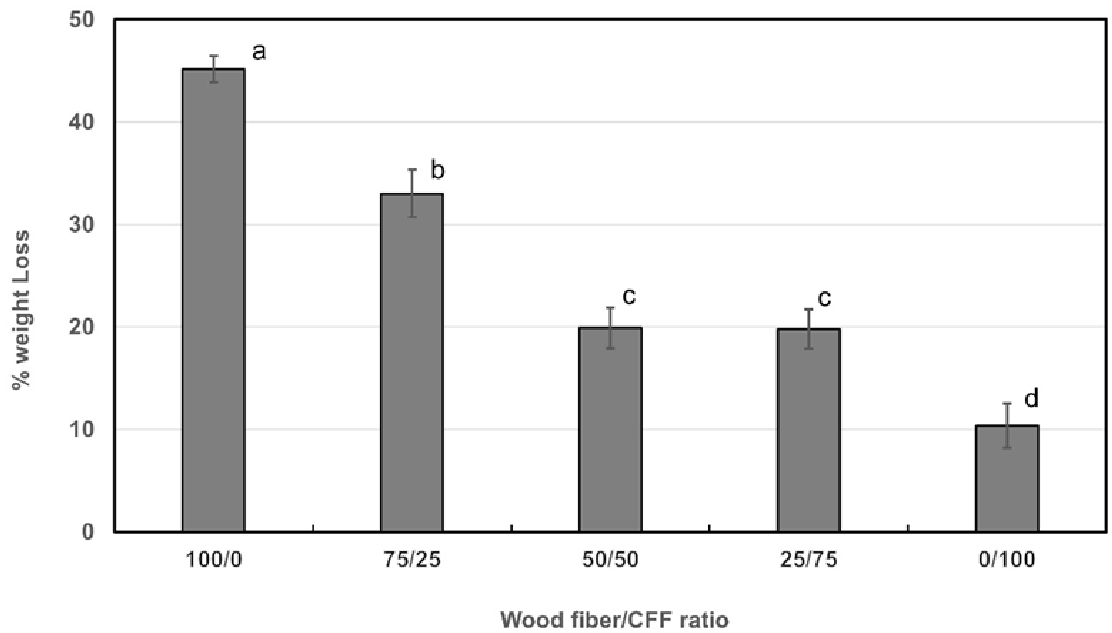

Fig. 3. Mean weight loss of HDF containing various ratios of wood fibers and CFF after 12 weeks of exposure to the white-rot fungus *P. sanguineus*; Bars followed by the same letter are not significantly different (Tukey's HSD test, α = 0.05)

Fig. 4. Decay resistance of HDF containing various ratios of wood fibers and CFF after 16 weeks of exposure to the white-rot fungus *P. sanguineus*

Mold Resistance

The susceptibilities of HDF specimen to molds after 4 weeks of incubation are shown in Table 1. All boards containing 25 to 100% CFF (*i.e.*, 75/25 to 0/100 ratio) showed moderate to heavy mold growth with slight variation among the specimens tested (Table 1, Fig. 5). Apparently, mixtures of wood fibers and CFF provided sufficient organic matter and nutrient-rich environment for mold growth and development. The hydrophilic nature of both wood fibers and keratin from CFF may have also trapped moisture from the surrounding that fueled mold growth (Kartal and Green 2003). However, HDF containing 100% wood fiber only (*i.e.*, 100/0 ratio) showed lower mold susceptibility (mold growth rating 1.67) compared with specimens containing higher CFF. The lower mold growth rating in HDF with 0% CFF (100% wood fiber) is consistent with lower moisture absorption. The results also suggest that HDF containing wood fibers and CFF may require a biocide with some anti-mold capability. The susceptibility to mold of HDF containing CFF could pose potential problems as mold contamination is increasingly encountered in insurance claims and health issues with the use of wood-based composites (Benthien *et al.* 2012).

Table 1. Mean Mold Growth Ratings of HDF Containing Various Ratio of Wood and Keratin Fibers after 4 Weeks of Exposure to *A. niger*, *P. chrysogenum*, and *T. viride*

Wood Fiber/CFF Ratio (by Weight)	Mold Growth Rating*
100/0	1.67 ± 0.67 a
75/25	3.83 ± 0.53 b
50/50	4.83 ± 0.07 c
25/75	4.00 ± 0.43 bc
0/100	4.33 ± 0.38 c

*Each value is the mean ± standard error of the mean (SE) of 12 independent ratings from 3 individuals. Means followed by the same letter are not significantly different (Tukey's HSD test, α = 0.05).

Table 2. Weight Loss of HDF Containing Various Ratio of Wood and CFF After 4 Weeks of Laboratory No Choice Feeding Test Against the Subterranean Termite *C. gestroi*

Wood Fiber/CFF Ratio	Weight Loss (%)*	Mortality (%)	
		Worker	Soldier
100/0	28.23 ± 3.16 d	18.55 ± 2.42 b	13.86 ± 2.51 b
75/25	15.12 ± 1.75 b	23.59 ± 2.32 c	19.67 ± 1.65 c
50/50	8.68 ± 1.23 a	17.68 ± 3.76 b	13.56 ± 0.34 b
25/75	13.54 ± 2.43 b	12.57 ± 1.34 a	7.69 ± 1.56 a
0/100	28.34 ± 2.45 c	34.58 ± 1.86 d	24.23 ± 1.72 c

*Each value is the mean ± SE of 5 replicates; means within a column followed by the same letter are not significantly different (Tukey's HSD test, α = 0.05)

Termite Resistance

Results of laboratory termite no choice feeding test of HDFs containing wood fibers and CFF against *C. gestroi* after 5 weeks of exposure are shown in Table 2. Average weight loss of HDFs with 25% to 100% CFF (*i.e.*, 75/25 to 0/100 ratio) ranged from about 8 to 15%, indicating that the boards were resistant to *C. gestroi*. Specimens showed surface nibbles to light attack by the termite after 5 weeks of exposure. Termite (worker) mortality was only about 12 to 23% in various HDF specimens, suggesting the high tolerance of *C. gestroi* to the various HDF compositions used in this study. In comparison, HDF made up of 100% wood fibers (100/0 ratio) sustained weight loss of around 28% exhibiting moderate attack and penetration with 34% termite mortality.

Observations also showed that black molds began to appear on all HDF specimens within 1 week after the beginning of the test. However, the molds did not appear to interfere with the ability of *C. gestroi* to consume the specimens. Similar observations were made by Kartal and Green (2003) while studying decay and termite resistance of MDF. The occurrence of mold on HDF specimens could be due to contamination and growth, aided by moisture trapped by HDF from the surrounding as described above.

Results of underground termite exposure tests of HDF specimens against active field colonies of Philippine subterranean termites after 16 weeks of exposure are shown in Table 3. Average weight loss for various HDF specimens containing 25% to 100% CFF (*i.e.*, 75/25 to 0/100 ratio) showed moderate resistance to termites, with weight loss ranging from about 19 to 28% from all sites used in this study (Table 3). In comparison, samples containing 100% wood fibers (*i.e.*, 0/100 ratio) sustained about 35 to 40% weight loss, indicating moderate to heavy termite damage to the specimens. Furthermore, moderate to heavy mold growth on HDF specimens were also observed during the early stages of the test (Fig. 6). This would support the observation that HDF containing wood fibers and CFF had no or limited mold resistance and would require the use of a biocide to prevent the occurrence of mold growth.

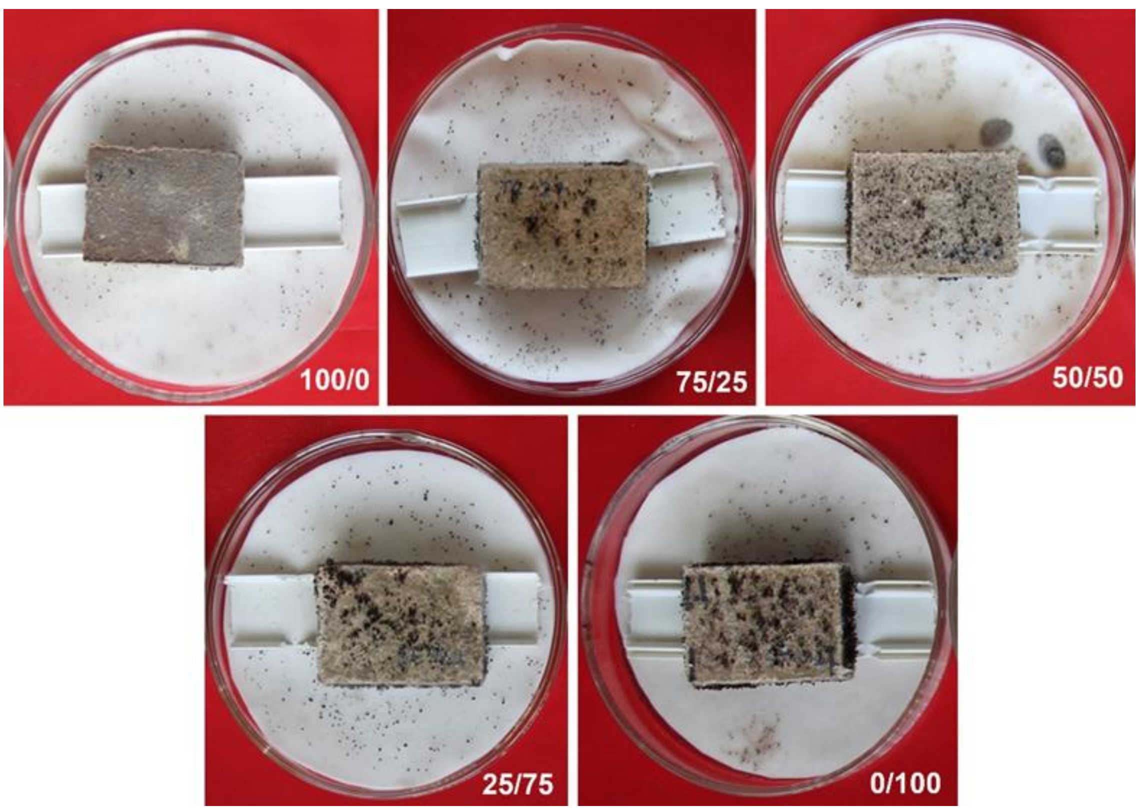

Fig. 5. Mold growth on HDF containing various ratio of wood fibers and CFF after 4 weeks of exposure to *A. niger*, *P. chrysogenum*, and *T. viride*

Table 3. Weight Loss of HDF Containing Various Ratio of Wood and Keratin Fibers After 16 Weeks of Underground Exposure to Subterranean Termites

Wood Fiber/CFF Ratio	Weight Loss (%)*		
	Site 1	Site 2	Site 3
100/0	38.14 ± 2.15 a	40.28 ± 3.22 a	35.42 ± 4.31 a
75/25	20.10 ± 4.75 b	26.54 ± 3.42 b	28.42± 5.25 b
50/50	25.17 ± 1.46 c	21.18 ± 1.72 c	23.76 ± 4.24 b
25/75	19.75 ± 1.83 bc	26.67 ± 1.34 b	13.19 ± 2.53 c
0/100	23.15 ± 0.86 c	22.35 ± 2.32 c	27.16 ± 2.41 b

*Each value is the mean ± SE of 3 replicates; mean within a column followed by the same letter are not significantly different (Tukey's HSD test, α = 0.05)

Fig. 6. Mold growth on HDF specimens containing various ratio of wood and CFF after 1 week of underground exposure against Philippine subterranean termites

CONCLUSIONS

1. The study showed that the proportion of wood fibers and chicken feather fibers (CFF) had significant effect on the decay, mold, and subterranean termite resistance of high density fiberboard (HDF) in both laboratory and field exposure tests.
2. The HDF specimens containing 50% to 100% CFF were moderately to highly resistant to the white-rot fungus *Pycnoporus sanguineus* and the subterranean termite *Coptotermes gestroi*.
3. Moderate to heavy mold growth was observed on HDF containing 25% to 100% CFF when inoculated with a mixed strain of *Aspergillus niger*, *Penicillium chrysogenum*, and *Trichoderma viride*.
4. In general, HDF consisting of wood fibers and CFF was resistant to decay and subterranean termite but susceptible to mold growth. The susceptibility HDF to mold may require the use of a biocide to improve mold resistance.

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