Biological Performance of Novel Hybrid Green Composites Produced from Glass Fibers and Jute Fabric Skin by the VARTM Process

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Environmentally friendly composites are increasingly used in building applications that require fungal and insect resistance. This study evaluated the ability of both wood-degrading and mold fungi to decompose hybrid composites made of wood furnish, glass fibers, and jute fabric skin. Fungal decay resistance tests employed brown-rot fungus (*Fomitopsis palustris*) and white-rot fungus (*Trametes versicolor*). Mold resistance tests were performed with a mixture of three mold fungi, *Aspergillus niger*, *Penicillium chrysogenum*, and *Trichoderma viride*. The test specimens were also bio-assayed against termites in both laboratory and field conditions. When compared to control composites specimens produced by conventional methods without glass fiber and jute, the specimens with/without glass fiber and jute fabric manufactured by the VARTM process showed high resistance against the wood-degrading fungi and termites under laboratory and field conditions; however, mold fungal growth was observed on the surfaces of the specimens with 10%, 15%, and 20% glass fiber (without jute fabric) and with 5%, 10%, and 15% glass fiber (with jute fabric). In geographical locations with severe decay and termite hazards, these composite products may have a long service life as alternatives to conventional composites.

Keywords: Green composites; Hybrid composites; Biological performance; Decay; Termite; Mold

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INTRODUCTION

Biodegradable and renewable composites are a response to the important issues of sustainability and environmental impact. The use of renewable resources, such as plant-based materials, reduces the dependence on shrinking natural resources such as wood (Satyanarayana 2015). Plant-derived composites, *i.e.*, lignocellulosics, have numerous applications and are being converted into value-added materials (Ashori 2008; Shah 2013; Hamouda *et al.* 2015, Garcia-Garcia *et al.* 2016; García *et al.* 2016; Hassanin *et al.* 2016a; Katogi *et al.* 2016; Nurul Fazita *et al.* 2016; Wang and Shih 2016).

Due to their biological nature, lignocellulosic composite materials are susceptible to attack by microorganisms (Curling and Murphy 1999; Kartal and Green III 2003). Although environmentally friendly composites are likely to have acceptable mechanical and physical properties compared with other conventional wood-based composites, their biological performance is important when they are used in harsh environments. The

biological resistance of composites highly depends on fibers, fillers, resin, and other binding materials used in board manufacturing. The incorporation of naturally durable plant fibers in manufacturing processes may increase the resistance to biological attack (Barnes and Amburgey 1993; Evans *et al.* 1997; Kard and Mallette 1997; Evans *et al.* 2000; Kartal and Green III 2003). However, bio-composites also depend on resins and other binding materials for their integrity, and failure in these binding materials can greatly affect the resistance of the entire composite to biological degradation (Wagner *et al.* 1996; Vick *et al.* 1996; Carll and Highley 1999; Kartal and Clausen 2001). Renewable fiber-reinforced polymer composite materials are increasingly popular in various applications in construction, the automotive industry, *etc*. In addition to interior usage, the use of hybrid composites in particularly high-decay-hazard environments is likely to grow. However, little information is available on the resistance of fiber-reinforced hybrid composites to microbial biodegradation. Impurities, additives, fibers, and other materials in the production process may promote fungal and bacterial growth because such materials are a source of carbon and energy for microorganisms (Tascioglu *et al.* 2003).

This study evaluates the biological resistance of hybrid green composite boards previously tested for their mechanical and physical properties (Hassanin *et al.* 2016b). The core portion of the composite board was reinforced with short glass fibers. The prepared composites were also supported with woven jute fabrics. The vacuum assisted resin transfer molding (VARTM) technique was used to combine the core board and woven jute skin. Due to their high availability, glass fibers are generally used as reinforcement in fiber-reinforced composites. Jute is a cellulosic natural fiber and can be processed to manufacture diverse textiles, usually in the form of woven fabrics. In addition to their renewability, these natural plant fibers are non-toxic and cost-effective materials for composite products. In this study, fungal decay and mold resistance tests were performed in laboratory conditions. Both laboratory and field termite resistance tests were used to evaluate the insect resistance of the produced hybrid-composite boards.

EXPERIMENTAL

Materials

The particle mixture used to manufacture hybrid composites was composed of maritime pine (*Pinus pinaster*), mixed pine, oak (*Quercus* spp.), and poplar (*Populus* spp.) woods (25%, by weight) and was supplied by Kastamonu Integrated Wood Industry Inc., Gebze, Kocaeli, Turkey. Urea formaldehyde resin and ammonium chloride were used as a hardener.

Short glass fibers (12 mm) were also used as reinforcement. Unsaturated polyester resin (BRE310) was purchased from Boytek (Istanbul, Turkey). The final resin composition contained 0.5% w/w cobalt octate as the accelerator and 1 wt.% methyl ethyl ketone peroxide (MEKP) as the initiator. The jute fabric had a balanced plain weave 1/1 structure with an areal density of 280 g/m^2.

Manufacturing Methods

Hybrid composites

Two main procedures were followed to produce hybrid composites. In the first, particleboards with an average target density of 310 kg/m^3 were prepared using the

formaldehyde and wood particle-glass mixture, which was hot-pressed in mild conditions. The wood particle mixture was composed of maritime pine (*Pinus pinaster*, 45% by weight), mixed pine (35% by weight), oak, and poplar woods (20% by weight). The particles were mixed with urea formaldehyde resin and ammonium chloride as a hardener. The mixing procedure was repeated several times to ensure the distribution of the resin within the wood particles. Short glass fibers (12 mm) were used as reinforcement. In total, 10 filler compositions were prepared by mixing wood particles and short glass fibers at different ratios between 0% and 20% by weight. Mixing was repeated several times to ensure a homogenous distribution of the short glass fibers. Homogenously mixed mats were hot pressed at 8 bar and 180 °C for 7 min in a laboratory scale hot press. The obtained panels had dimensions of 40 mm x 40 mm x 10 mm. Particleboard panels were conditioned in a climate chamber at 65% relative humidity (RH) and 20 °C.

Table 1. Composition of Hybrid Green Composites

Composite Specimen Group	Glass Fiber Content (%)	Jute Fabric Skin
WR0G*	0	No
WR5G	5	No
WR10G	10	No
WR15G	15	No
WR20G	20	No
WR0GJ	0	Yes
WR5GJ	5	Yes
WR10GJ	10	Yes
WR15GJ	15	Yes
WR20GJ	20	Yes
*W: wood, G: short glass fibers, J: jute		

This process was followed by a second procedure, where the sandwich hybrid composites were prepared using the vacuum-assisted resin transfer molding (VARTM) technique in a closed mold. A detailed procedure is described in Hassanin *et al.* (2016a, b). Vacuum was applied to facilitate unsaturated polyester resin flow into the particleboard mat. After the impregnation, the composite cured at room temperature (Xia *et al.* 2015). Unsaturated polyester resin (BRE310) was purchased from Boytek (Istanbul, Turkey). The final resin contained 0.5% (w/w) cobalt octate as the accelerator and 1 wt.% methyl ethyl ketone peroxide (MEKP) as the initiator.

For the fabrication of hybrid composites, woven jute fabrics acquired from local stores were used as the skin layers. The jute fabric had a balanced plain weave 1/1 structure with an areal density of 280 g/m^2. The obtained jute fabric had almost equal mechanical properties in both warp and weft directions. The average breaking force and extension for jute fabric in warp and weft directions were 526.5 N and 5.8%, respectively. Of the 10 composite groups, five were covered with jute fabrics. The samples were cured at room temperature for 25 min.

The compositions of the samples are given in Table 1. The samples were named according to presence of wood (W), short glass fibers (G), and jute (J). The first 5 samples

did not contain a skin layer of jute fabric, whereas the top and the bottom layers of the next 5 were covered with woven jute fabrics by the VARTM process.

Conventional composites - controls

Conventional particleboard specimens to be served as controls were prepared using the traditional hot press technique. Particleboard panels were designed in a single layer with a target density of 660 kg/m^3. The raw materials consisted of 65% softwood and 35% hardwood particles by weight. Urea-formaldehyde (UF) resin at the 10% adhesive level by oven-dry weight was used based on the oven-dry weight of wood particles. One-percent ammonium chloride (NH_4Cl) by weight was added to the resin as a hardener. The particles were placed in a drum blender and sprayed with UF resin and NH_4Cl for 5 min to obtain a homogenized mixture. The conventional composites had a thickness of 10 mm and an average density of 0.66 g/cm^3.

Tests

Fungal decay resistance tests

Two Basidiomycetes—brown-rot fungus, *Fomitopsis palustris* (Berk. & M.A. Curtis) Gilb. & Ryvarden (TYP 0507), white-rot fungus, *Trametes* (*Coriolus*) *versicolor* (L.:Fr.) Pilat (COV 1030)—were used in decay tests. The decay resistance of composite specimens (20 mm × 20 mm × 10 mm) was evaluated by inserting the specimens directly into Petri dishes inoculated with Basidiomycetes fungi. Before decay testing, all specimens were dried at 60 °C for 3 days. The fungi were inoculated on 2% malt extract agar (MEA) in Petri dishes separately for 3 weeks at 23 °C before placement of the specimens into the dishes. The specimens were autoclaved at 121 °C and 15 psi for 20 min for sterilization and then placed into the inoculated Petri dishes. One specimen was placed in each dish, and conventional composite specimens served as controls. Sixteen specimens were used for each specimen group and each fungus. After a 12-week incubation period in a temperature and humidity-controlled chamber at 26 °C and 65% RH, the specimens were dried at 60 °C for 3 days and weighed to calculate weight losses based on the weights of the specimens before and after decay resistance tests.

Mold fungi resistance tests

Three mold fungi—*Aspergillus niger* 2.242, *Penicillium chrysogenum* PH02, and *Trichoderma viride* ATCC 20476—were used in mold tests. Composites by the VARTM process and control (conventional composites) specimens (20 mm × 70 mm x thickness) were evaluated for resistance to mold fungi according to a modified ASTM D 4445-10 (2015) protocol. The mold fungi were grown on 2% malt agar (Difco, Detroit, MI, USA) at 27 °C and 80% RH. All fungi were obtained from the USDA Forest Service Forest Products Laboratory, Madison, WI, USA. A mixed spore suspension of the three test fungi were prepared by washing the surface of individual 2-week-old Petri plate cultures with 10 to 15 mL of sterile DI water. Washings were combined in a spray bottle and diluted to approximately 100 mL with DI water to yield approximately 3 x 10^7 spores/mL. The spray bottle was adjusted to deliver 1 mL of inoculum per spray. The specimens were sprayed with 1 mL of mixed mold spore suspension and incubated at 27 °C and 80% RH for 4 weeks. Following incubation, the specimens were visually rated on a scale of 0 to 5 with 0 indicating the specimen is completely free of mold growth and 5 indicating the specimen was completely covered with mold growth (0: no growth, 1: 20%, 2: 40%, 3: 60%, 4: 80%,

5: 100% coverage with mold fungi).

Laboratory termite resistance tests

The subterranean termites *Coptotermes curvignathus* Holmgren (Order Isoptera, Family Termitidae) were used in laboratory tests for termite resistance. The tests were carried out based on the Indonesian National Standard SNI 01.7207 (2006). Table 2 summarizes the test method in the mentioned standard.

Table 2. General Description of Laboratory Termite Resistance Tests

Item	Descriptions
General description	No choice test
Test termite species	*Coptotermes curvignathus* Holmgren
Number of termites used per test unit	200 workers
Wood specimens	Species: Not specified for control wood
	Size: 2.5 cm (L) × 2.5 cm (T) × 0.5 cm (dressed sawn)
Pre- and post-conditioning of wood specimens	Oven-drying at 102 ± 3 °C until no weight change detected
Weathering procedure	-
Test container	Round jam pot (450 mL to 500 mL capacity) with a wide-mouth and a bottom area of 25 cm^2 to 30 cm^2
Test assembly	An individual wood specimen buried in 200 g sand at 7% MC below water holding capacity of the sand (or moist sand) in the jam pot so that one of the largest areas of the sample (the widest part) allowed to contact inside vertical wall of the pot.

A composite specimen (25 mm × 25 mm × 10 mm) was placed in a glass jar, leaning against a sidewall with 200 g sand (7% moisture content under water holding capacity of the sand) and 200 healthy and active workers of *C. curvignathus*. Conventional composites and solid wood from Scots pine sapwood specimens served as controls. The jam pots were placed in a dark room for 4 weeks, and the bottles were weighted weekly to regulate the moisture content of the sand. In cases where the moisture content of the sand was reduced by 2% or more, water was added to reach the moisture content stated in the standard. Resistance to subterranean termites according to the Indonesian National Standard SNI 01.7207 (2006) is given in Table 3. Each test specimen was examined and visually rated using a rating system given in Table 4.

Table 3. Termite Resistance Classes Based on Weight Losses

Sample Condition	Weight Loss (%)	Resistant Class
Very resistant	< 3.52	I
Resistant	3.52 – 7.50	II
Moderate	7.50 – 10.96	III
Poor	10.96 – 18.94	IV
Very poor	> 18.94	V

Table 4. Rating System for Visual Evaluations of Termite Resistance*

Visual Evaluation	Rating
Sound, surface nibbles permitted	10
Light attack	9
Moderate attack, penetration	7
Heavy	4
Failure	0
*Based on ASTM D 3345-08 (2008)	

Field termite tests

The tests were performed in South Sulawesi, Indonesia, which has an average annual rainfall of 2875 mm and annual temperature of 31 °C. The test area has a typical tropical climate and shows heavy attacks of *Coptotermes* sp. The exposure test involved laying a test specimen (20 mm × 10 mm × 100 mm) on top of hollow concrete blocks standing on the soil surface and then covering the structures with a PVC pipe cap to protect the sample from rain and to maintain high humidity. There was no direct contact between the specimen and the soil, other than that brought about by the termites to construct shelter tubes. Through the two perforations in each block, 25 mm × 25 mm × 300 mm pine (*Pinus merkusii*) feeder stakes were driven into the ground so that the top of the stake was within 2 to 5 mm of the top of the concrete block. The test specimens were situated one per block such that they covered the holes in the block but were not in direct contact with the feeder stake. This design prevented direct tunneling by termites from the untreated wood stakes into the test samples. Conventional composite specimens served as controls. After six weeks of exposure, each specimen was carefully removed, examined, and visually rated.

Statistical evaluations

Weight losses from decay and termite resistance tests and mold ratings were statistically analyzed by the Student's *t*-test (inerSTAT-a v1.3) for the composite groups. One-way analysis of variance (ANOVA) was conducted by the inerSTAT-a V.1.3 program, and *p* and F values were calculated (Vargas 1999).

RESULTS AND DISCUSSION

The final thickness of the produced hybrid green composites was 10 mm, and their average density was 1000 kg/m^3. This result confirmed that a sandwich structure with or without jute fabric layers bonded to the light particleboard core (density, 310 kg/m^3) was constructed by the VARTM process.

The average weight losses of test specimens exposed to *T. versicolor* and *F. palustris* fungi for 12 weeks and the statistical significance among the composite groups are given in Fig. 1 and Table 5.

When compared to conventional composite specimens (controls), the hybrid composite specimens by the VARTM process showed apparently increased fungal resistance and those specimens had statistically significant differences ($p<0.01$). However, there was no close relationship between weight losses and types of the hybrid composites by the VARTM process.

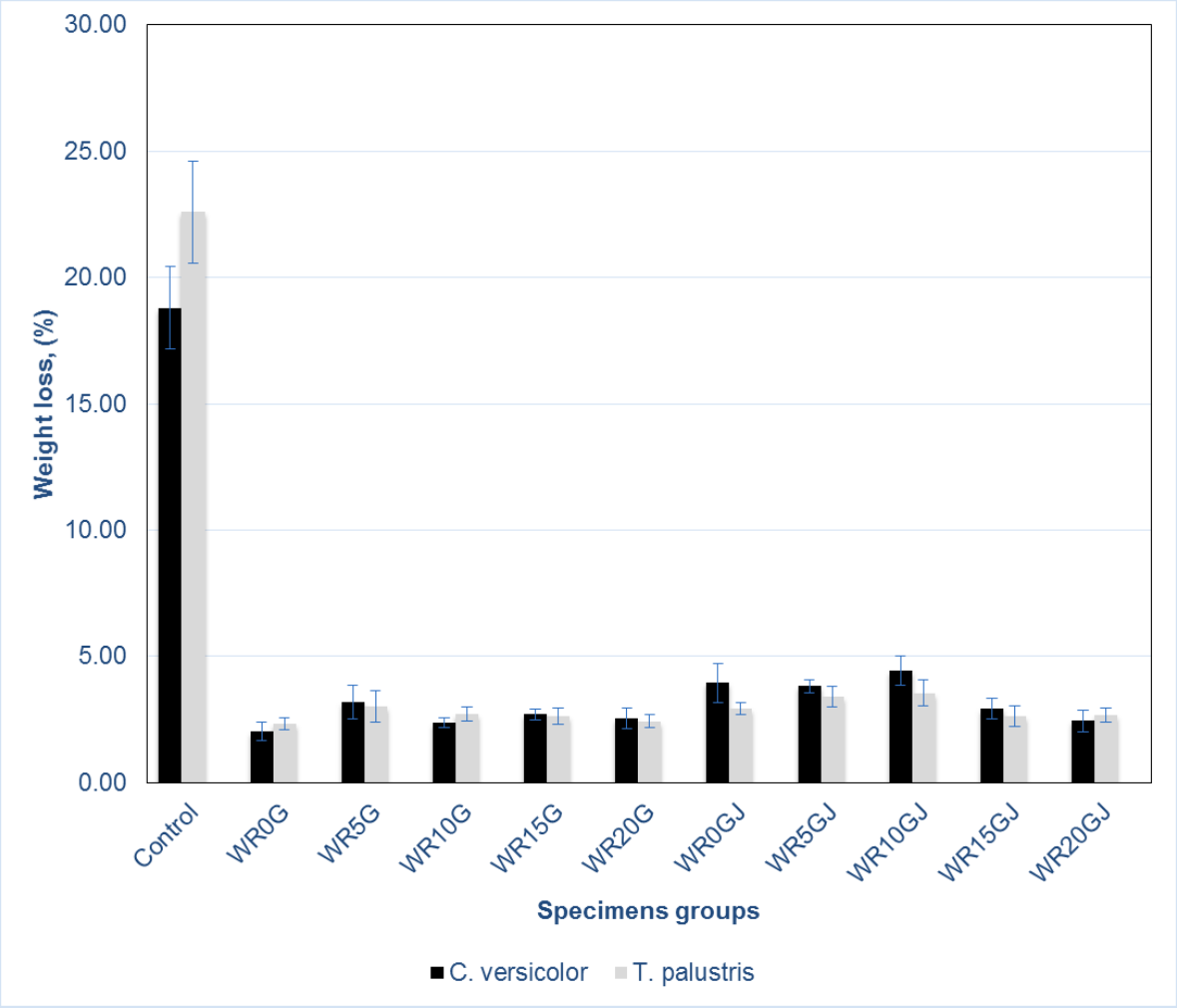

Fig. 1. Weight losses after 12-week-fungal resistance tests (W: wood, G: short glass fibers, J: jute)

Weight losses in the hybrid composite specimens varied between 1.98% and 4.44%. In general, there were slightly higher weight losses in the specimens containing either glass fiber only or glass fiber plus jute fabrics than in the WR0G specimens. Statistically significant differences were observed in the specimens from the WR5G, WRG0J, WRG5J, and WRG10J composite groups compared with the WR0G specimens for all test fungi. However, increased glass fiber content in the specimens with jute fabric (WR20GJ) decreased the weight losses to the amounts similar to the WR0GJ specimens. In most specimens, jute fabric caused slight increases in weight losses compared with the non-fabric composite groups. According to ASTM D 2017-05 (2010) (Table 6), the hybrid green composite specimens by the VARTM manufacturing process were classified as "highly resistant" to the fungi tested even though this classification is generally applied to solid wood specimens.

Table 7 shows mold ratings in the specimens after a 4-week exposure to the mold fungi. The levels of statistical significance among the composite groups are given in Table 8.

Table 5. Statistical Evaluations of Weight Losses Occurred in the Composite Groups by the *T. versicolor* and *T. palustris* Fungi According to the ASTM D 2017-05 (2010) Standard Test Method

Q values from pairwise means												
Specimens	**Control**	**WR0G**	**WR5G**	**WR10G**	**WR15G**	**WR20G**	**WR0GJ**	**WR5GJ**	**WR10GJ**	**WR15GJ**	**WR20GJ**	p values 2 tailed *T.versicolor* ONE-WAY ANOVA F: 521.2329 p: 6.88E-81
Control		79.670	74.070	77.961	76.395	77.107	70.464	71.128	68.139	75.352	77.629	
WR0G	p<0.01		-5.599	-1.708	-3.274	-2.562	-9.205	-8.541	-11.530	-4.318	-2.040	
WR5G	p<0.01	p<0.01		3.891	2.325	3.037	-3.606	-2.942	-5.931	1.281	3.559	
WR10G	p<0.01	n.s.	n.s.		-1.566	-0.854	-7.497	-6.833	-9.822	-2.610	-0.332	
WR15G	p<0.01	n.s.	n.s.	n.s.		0.712	-5.931	-5.267	-8.256	-1.044	1.234	
WR20G	p<0.01	n.s.	n.s.	n.s.	n.s.		-6.643	-5.979	-8.968	-1.756	0.522	
WR0GJ	p<0.01	p<0.01	n.s.	p<0.01	p<0.01	p<0.01		0.664	-2.325	4.887	7.165	
WR5GJ	p<0.01	p<0.01	n.s.	p<0.01	p<0.05	p<0.01	n.s.		-2.989	4.223	6.501	
WR10GJ	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01	n.s.	n.s.		7.212	9.490	
WR15GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.	p<0.05	n.s.	p<0.01		2.278	
WR20GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.	p<0.01	p<0.01	p<0.01	n.s.		
Q values from pairwise means												
Specimens	**Control**	**WR0G**	**WR5G**	**WR10G**	**WR15G**	**WR20G**	**WR0GJ**	**WR5GJ**	**WR10GJ**	**WR15GJ**	**WR20GJ**	p values 2 tailed *T. palustris* ONE-WAY ANOVA F: 399.1592 p: 2.77E-75
Control		67.812	65.503	66.507	66.775	67.511	65.838	64.165	63.730	66.808	66.641	
WR0G	p<0.01		-2.308	-1.305	-1.037	-0.301	-1.974	-3.647	-4.081	-1.004	-1.171	
WR5G	p<0.01	n.s.*		1.004	1.271	2.007	0.335	-1.338	-1.773	1.305	1.137	
WR10G	p<0.01	n.s.	n.s.		0.268	1.004	-0.669	-2.342	-2.777	0.301	0.134	
WR15G	p<0.01	n.s.	n.s.	n.s.		0.736	-0.937	-2.609	-3.044	0.033	-0.134	
WR20G	p<0.01	n.s.	n.s.	n.s.	n.s.		-1.673	-3.345	-3.780	-0.703	-0.870	
WR0GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.		-1.673	-2.108	0.970	0.803	
WR5GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		-0.435	2.643	2.476	
WR10GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		3.078	2.911	
WR15GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		-0.167	
WR20GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		
*non-significant, n:10												

Table 6. Decay Resistance Expressed Either Weight Loss or Residual Weight (ASTM 2010)

Average Weight Loss (%)	Indicated Class of Resistance to Specified Test Fungus
0-10	Highly resistant
11-24	Resistant
25-44	Moderately resistant
45 or above	Slightly resistant or nonresistant

Table 7. Mold Ratings Occurred in the Composite Groups

Specimen Groups	Mold Ratings
Conventional composites (controls)	5.0 (0)
WR0G	2.0 (0.71)
WR5G	1.0 (0.00)
WR10G	4.1 (1.24)
WR15G	2.9 (0.22)
WR20G	4.9 (0.22)
WR0GJ	1.0 (0.61)
WR5GJ	5.0 (0.00)
WR10GJ	5.0 (0.00)
WR15GJ	5.0 (0.00)
WR20GJ	1.9 (1.14)

Note: Mold growth rating in pine sapwood specimens: 5. Values in parentheses are standard deviations (n = 5).

The lowest mold growth rates were exhibited by specimens with the two lowest glass fiber contents without jute skin. Incorporation of glass fibers at 10%, 15%, and 20% loading levels increased mold growth in the specimens. In the specimens with jute fabric skin, the lowest mold growth rates were observed in both the lowest and highest glass fiber-containing specimens. The specimens with 5%, 10%, and 15% glass fiber and jute fabric and conventional composites as controls were completely covered by fungal growth at the end of the exposure period.

Average weight losses, visual evaluation ratings, and percentage survival of termites of the specimens during the termite bioassays (laboratory and field tests) and the levels of statistical significance among the composite groups (weight losses only) are shown in Tables 9 and 10, respectively.

Conventional composite specimens as controls showed much higher weight losses and lower V-rating and mortality values compared to the VARTM process-produced hybrid composites in both laboratory and field termite resistance tests. Thus, there were statistically significant differences ($p<0.01$) between conventional composites (controls) and hybrid composites by the VARTM process.

Table 8. Statistical Evaluations of Mold Ratings in the Composite Groups

Q values from pairwise means												p values 2 tailed Mold Resistance Test ONE-WAY ANOVA F: 41.7826 p: 3.51E-19
Specimens	**Control**	**WR0G**	**WR5G**	**WR10G**	**WR15G**	**WR20G**	**WR0GJ**	**WR5GJ**	**WR10GJ**	**WR15GJ**	**WR20GJ**	
Control		11.398	15.197	3.419	7.979	0.380	15.197	0.000	0.000	0.000	11.778	
WR0G	p<0.01		3.799	-7.979	-3.419	-11.018	3.799	-11.398	-11.398	-11.398	0.380	
WR5G	p<0.01	n.s.		-11.778	-7.219	-14.817	0.000	-15.197	-15.197	-15.197	-3.419	
WR10G	n.s.	p<0.01	p<0.01		4.559	-3.039	11.778	-3.419	-3.419	-3.419	8.359	
WR15G	p<0.01	n.s.	p<0.01	n.s.		-7.599	7.219	-7.979	-7.979	-7.979	3.799	
WR20G	n.s.	p<0.01	p<0.01	n.s.	p<0.01		14.817	-0.380	-0.380	-0.380	11.398	
WR0GJ	p<0.01	n.s.	n.s.	p<0.01	p<0.01	p<0.01		-15.197	-15.197	-15.197	-3.419	
WR5GJ	n.s.	p<0.01	p<0.01	n.s.	p<0.01	n.s.	p<0.01		0.000	0.000	11.778	
WR10GJ	n.s.	p<0.01	p<0.01	n.s.	p<0.01	n.s.	p<0.01	n.s.		0.000	11.778	
WR15GJ	n.s.	p<0.01	p<0.01	n.s.	p<0.01	n.s.	p<0.01	n.s.	n.s.		11.778	
WR20GJ	p<0.01	n.s.	n.s.	p<0.01	n.s.	p<0.01	n.s.	p<0.01	p<0.01	p<0.01		
*non-significant, n:10												

There was no significant effect of specimen composition of the VARTM-produced specimens on the susceptibility of specimens to termite attack during the termite bioassays when compared with the WR0G specimens in both laboratory and field tests. Weight losses, termite survival, and visual ratings were at good accordance in both laboratory and field tests. According to the Indonesian National Standard SNI 01.7207 (2006), all specimens produced by the VARTM process were classified as "very resistant" to termites based on the weight losses (Table 3).

There were no direct comparisons available in the literature, as studies on hybrid composites generally employ different types of fibers, reinforcing materials, and additives, and they follow diverse production methods. Tascioglu *et al.* (2003) evaluated fungal degradation of glass fiber/phenolic resin containing composites. Their results demonstrated that there was no weight loss in test specimens exposed to white and brown rot fungi; however, the specimens were susceptible to fungal penetration.

Table 9. Laboratory and Field Termite Resistance Tests

	Laboratory Termite Resistance Tests				Field Termite Resistance Tests	
Specimens	Weight Loss (%)	V-Rating*	Termite Mortality (%)		Weight Loss (%)	V-Rating
WR0G	2.20 (0.59)	9.60 (0.52)	23.10 (4.42)		2.41 (0.29)	9.50 (0.58)
WR5G	2.30 (0.36)	9.60 (0.52)	22.65 (3.38)		2.66 (0.26)	10.00 (0.00)
WR10G	2.01 (0.59)	9.60 (0.52)	22.90 (4.11)		3.43 (0.20)	10.00 (0.00)
WR15G	2.52 (0.24)	9.40 (0.52)	25.50 (3.14)		2.07 (0.20)	9.00 (0.00)
WR20G	2.61 (0.78)	9.60 (0.52)	25.30 (4.07)		2.15 (0.53)	10.00 (0.00)
WR0GJ	2.83 (0.45)	8.00 (1.05)	24.20 (3.07)		2.67 (0.38)	9.00 (0.00)
WR5GJ	2.52 (0.38)	9.50 (0.53)	24.00 (3.94)		2.08 (0.39)	10.00 (0.00)
WR10GJ	3.00 (0.46)	9.60 (0.52)	24.70 (3.43)		3.75 (0.27)	10.00 (0.00)
WR15GJ	2.62 (0.50)	9.60 (0.52)	23.40 (3.97)		2.17 (0.24)	10.00 (0.00)
WR20GJ	2.94 (0.58)	8.60 (0.84)	25.80 (3.24)		2.60 (0.38)	9.25 (0.50)
Control (solid wood)	12.45 (1.43)	5.20 (1.64)	15.60 (1.60)		-	-
Conventional composite specimens (controls)	21.7 (2.02)	1.3 (2.0)	10 (0.67)		15.33 (3.12)	2.4 (2.07)

*V- rating: Visual evaluation remark (see Table 4). Values in parentheses are standard deviations. n:10.

Table 10. Statistical Evaluations of Weight Losses Occurred in Both Laboratory and Field Termite Resistance Tests

Q values from pairwise means												
Specimens	**Control**	**WR0G**	**WR5G**	**WR10G**	**WR15G**	**WR20G**	**WR0GJ**	**WR5GJ**	**WR10GJ**	**WR15GJ**	**WR20GJ**	p values 2 tailed
Control		49.685	49.200	50.606	48.134	47.697	46.631	48.134	45.807	47.649	46.098	
WR0G	p<0.01		-0.485	0.921	-1.551	-1.987	-3.054	-1.551	-3.878	-2.036	-3.587	
WR5G	p<0.01	*n.s.		1.406	-1.066	-1.503	-2.569	-1.066	-3.393	-1.551	-3.102	
WR10G	p<0.01	n.s.	n.s.		-2.472	-2.908	-3.975	-2.472	-4.799	-2.957	-4.508	**Laboratory termite resistance tests**
WR15G	p<0.01	n.s.	n.s.	n.s.		-0.436	-1.503	0.000	-2.327	-0.485	-2.036	
WR20G	p<0.01	n.s.	n.s.	n.s.	n.s.		-1.066	0.436	-1.890	-0.048	-1.600	
WR0GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.		1.503	-0.824	1.018	-0.533	
WR5GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		-2.327	-0.485	-2.036	ONE-WAY ANOVA F: 211.3009 p: 4.19E-62
WR10GJ	p<0.01	n.s.	n.s.	p<0.05	n.s.	n.s.	n.s.	n.s.		1.842	0.291	
WR15GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		-1.551	
WR20GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		
Q values from pairwise means												
Specimens	**Control**	**WR0G**	**WR5G**	**WR10G**	**WR15G**	**WR20G**	**WR0GJ**	**WR5GJ**	**WR10GJ**	**WR15GJ**	**WR20GJ**	p values 2 tailed
Control		41.198	40.401	37.946	42.282	42.027	40.369	42.250	36.925	41.963	40.592	
WR0G	p<0.01		-0.797	-3.252	1.084	0.829	-0.829	1.052	-4.273	0.765	-0.606	
WR5G	p<0.01	n.s.		-2.455	1.881	1.626	-0.032	1.849	-3.476	1.562	0.191	
WR10G	p<0.01	n.s.	n.s.		4.337	4.082	2.423	4.305	-1.020	4.018	2.647	**Field termite resistance tests**
WR15G	p<0.01	n.s.	n.s.	n.s.		-0.255	-1.913	-0.032	-5.357	-0.319	-1.690	
WR20G	p<0.01	n.s.	n.s.	n.s.	n.s.		-1.658	0.223	-5.102	-0.064	-1.435	
WR0GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.		1.881	-3.444	1.594	0.223	
WR5GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		-5.325	-0.287	-1.658	ONE-WAY ANOVA F: 152.8623 p: 1.54E-55
WR10GJ	p<0.01	n.s.	n.s.	n.s.	p<0.05	p<0.05	n.s.	p<0.05		5.038	3.667	
WR15GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	p<0.05		-1.371	
WR20GJ	p<0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		
*non-significant, n:10												

Gon *et al.* (2012) stated that the intensity of blackish spots on the surface of jute-reinforced composites increased with increasing humidity. A slight appearance of localized black spots on the surfaces of test specimens was seen at 85% RH and grew significantly at 95% RH and immersed water conditions. In various studies by Gu *et al.* (1995a, b; 1996; 1997; 2011), various additives in fiber-reinforced composites stimulated microbial growth. These components in the composite matrix serve as carbon, nitrogen, and energy sources for microorganisms (Tascioglu *et al.* 2003). Tascioglu (2003) showed that a melamine resin binder with a high nitrogen content may have promoted microbial degradation in test specimens produced from glass fiber. In the recent study, in most cases jute fabric in the specimens increased slightly weight losses in the decay resistance tests when compared to jute-free specimens. Similar results were obtained when the specimens were exposed to fungi, suggesting that jute fabric may slightly improve microbial growth on the specimen surfaces. The main chemical constituents of jute are alpha-cellulose, hemicelluloses, and lignin (Rowell and Stout 1998; 2006). Jute also contains minor constituents such as nitrogenous matter (0.8% to 1.5%) that might contribute to microbial growth.

CONCLUSIONS

1. The hybrid composite specimens prepared by the VARTM process showed resistance against all decay fungi and termites in both laboratory and field tests when compared to control (conventional composites) specimens.
2. Mold fungi were able to grow on some hybrid composite specimens with 10%, 15%, and 20% glass fiber without jute fabric and 5%, 10%, and 15% glass fiber with jute fabric and control specimens as well.
3. Hybrid composite products may be useful in regions of severe decay and termite hazard, while mold fungi can grow on the surfaces of some specimen groups.

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