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Tsuyoshi Yoshimura · Munezoh Takahashi

Biological resistance of Zn-Al metal-coated wood

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Abstract Sapwood blocks of sugi (*Cryptomeria japonica*) and akamatsu (*Pinus densiflora*) were coated with Zn/Al (45%/55%) alloy metal at thicknesses of 20–30, 90–100, and 180–200μm by an arc spray gun. They were served for choice and no-choice tests with a brown rot fungus (*Fomitopsis palustris*), a white rot fungus (*Trametes versicolor*), and a pest termite (*Coptotermes formosanus*). Coating thickness of 20–30μm was enough to prevent attacks by both test fungi, whereas 90–100μm thickness was needed for protection against termite attacks. Exfoliation of the coating layers was observed during the wet–dry process in the tests. The results suggested that Zn-Al alloy metal coating treatment was applicable as an alternative method for the protection of timbers from biological deterioration when combined with an additional treatment creating a vapor barrier.

Key words Metal-coated wood · Zn-Al alloy · Biological resistance · Decay fungi · Termite

Introduction

Biological deterioration is an important factor that affects the durability of wooden houses.[1] In addition, recent expansionary use of exterior wood and wood-based materials has been promoting research efforts on the improvement of biological resistance of the materials as well as weathering resistance.[2]

During the course of developing alternative methods for controlling the biological deterioration of wood and wood-based materials with less use or nonuse of chemicals, surface metal coating treatment should be investigated, as well as chemical modification.[3] Hasegawa et al. investigated the biological resistance of electroless plating of wood with nickel and copper and found that the plated wood samples satisfactorily prevent attacks by a white rot fungus, *Coriolus versicolor* (*Trametes versicolor*), and a termite, *Coptotermes formosanus*.[4]

The Zn/Al (45%/55%) alloy metal coating has been applied to protect rust in many iron heavy constructions such as bridges and ships. It acts with combined effects: the galvanic corrosion of zinc against iron and the barrier effect of aluminum. Many iron-based fittings are used in wooden houses, particularly in crawl spaces and inside walls where biological deterioration preferentially occurs. Therefore, application of the metal coating in these areas seems to be useful for improving the durability of not only the metal fittings but also the wooden materials. This is true for the exterior wood and wood-based materials as well. In this paper, we report the biological resistance of wood blocks spray-coated with Zn/Al (45%/55%) alloy metal.

Materials and methods

Samples

Sapwood blocks of sugi (*Cryptomeria japonica* D. Don), measuring 20mm (R) × 20mm (T) × 10mm (L), and those of akamatsu (*Pinus densiflora* Sieb. et Zucc.), measuring 10mm (R) × 10mm (T) × 20mm (L), were used for decay tests and termite tests, respectively. They were coated with Zn/Al (45%/55%) alloy metal at thicknesses of 20–30μm (A), 90–100μm (B), and 180–200μm (C) by arc-melting spray. The coating thickness was controlled by the spraying period. Some of the treated samples were weathered by the following procedure: The samples were water-soaked in a glass beaker and gently stirred (400–450rpm) for 8h at 25° ± 2°C, after which they were dried for 16h at 60°C. This procedure was repeated nine times.

T. Yoshimura (✉) · M. Takahashi
Wood Research Institute, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan
Tel. +81-774-38-3662; Fax +81-774-38-3664
e-mail: tsuyoshi@termite.kuwri.kyoto-u.ac.jp

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Decay tests

Decay resistance of Zn/Al-coated wood was evaluated by a choice test and a no-choice test. The choice test was carried out as follows: A brown rot fungus, *Fomitopsis palustris* (Berk. Et Curt.) Gilbn. & Ryv. FFPRI 0507, and a white rot fungus, *Trametes versicolor* (L.: Fr.) Pilat FFPRI 1030, were monocultured in glass chambers (90 × 220 × 100 mm) with 2.0% agar medium containing 4.0% glucose, 0.3% peptone, and 1.5% malt extract for *F. palustris* and half of each of these concentrations for *T. versicolor*. Twenty not-weathered oven-dried samples (five each for treating strength and five for untreated controls) were randomly arranged in the chamber on a plastic mesh (*F. palustris*) or without a mesh (*T. versicolor*). Two chambers were employed for each fungus so a total of 10 replicates were tested. After 6 weeks' exposure to the fungi at 26° ± 2°C in the dark, the samples were recovered, washed, and oven-dried. Mass losses were calculated by comparing the oven-dried sample masses before and after the test.

A no-choice test was done according to JIS K-1571 (1998) using not-weathered samples and weathered samples. Because the lowest treating strength (A: 20–30 μm coating thickness) could not protect against termite invasion in the no-choice test (see below), the samples with stronger treating strength (B and C) were used for this test. The fungi were monocultured in glass bottles (900 ml) with 250 g quartz sand and 80–85 ml liquid medium (concentrations of nutrients were the same as in the choice test). Three samples were set on a mycelial mat in a bottle with a plastic mesh (*F. palustris*) or without a mesh (*T. versicolor*). After 12 weeks' exposure to the fungi at 26° ± 2°C in the dark, the samples were recovered, washed, and oven-dried. Mass losses were calculated by comparing the oven-dried sample masses before and after the test. Three bottles of not-weathered samples or two bottles of weathered samples were employed for each fungus and each treating strength, so the nine not-weathered samples and the six weathered samples were tested.

Termite tests

A choice test and a no-choice test were employed for evaluating termite resistance of Zn-Al spray-coated wood. A choice test was conducted using a laboratory colony of *Coptotermes formosanus* Shiraki maintained more than 10 years in the dark at 28° ± 2°C and more than 85% relative humidity (RH). Twenty not-weathered oven-dried samples (five each for treating strength and five for untreated controls) were randomly arranged and sandwiched by akamatsu lumber. The assembled test set was placed on the laboratory colony for 3 weeks (test I) or 15 weeks (test II). For test II, only samples with the stronger treating strength (B and C) were used because termites penetrated wood samples treated with the lowest strength (A) in the no-choice test (see below). After the desired test duration, the samples were recovered, washed, and oven-dried. Mass losses were calculated by comparing the oven-dried sample masses before and after exposure to the colony.

Japan Wood Preserving Association (JWPA) Standard 11(1)-1992 was employed as a no-choice test method. An oven-dried sample was placed on the center of the plaster bottom of an acrylic cylindrical container (80 mm diameter, 60 mm height) with 150 workers and 15 soldiers of *C. formosanus*. The assembled container was placed on a damp cotton pad so the termites could take up water through the plaster bottom and was maintained for 3 weeks in the dark at 28° ± 2°C and more than 85% RH. Mass losses were calculated by comparing the oven-dried sample masses before and after exposure to termites. Five replicates were used for each treating strength.

Results

Decay resistance

Table 1 shows the results of the choice and the no-choice tests of decay resistance. In the choice test 6 weeks' exposure of the untreated blocks to *F. palustris* resulted in more than 40% mean mass loss, whereas the Zn-Al spray-coated wood blocks performed well against *F. palustris*, showing no mass losses after the test. The mean mass loss of the untreated wood blocks after 6 weeks' exposure to *T. versicolor* was 2.3% and the samples coated with the lowest treating strength (A) had a 1.0% mean mass loss. The

Table 1. Decay resistance of Zn/Al (45%/55%) spray-coated sugi sapwood blocks

Condition	Percent mean mass loss (SD)			
	Untreated	A (20–30 μm)	B (90–100 μm)	C (180–200 μm)
Choice test				
F. palustris (NW)	42.8 (3.19)	0	0	0
T. versicolor (NW)	2.3 (0.82)	1.0 (1.31)	0	0
No-choice test				
F. palustris				
W	NT	NT	0	0
NW	50.3 (5.44)	NT	0	0
T. versicolor				
W	NT	NT	0	0
NW	25.3 (3.90)	NT	0.7 (0.33)	0

NT, not tested; W, weathered; NW, not weathered

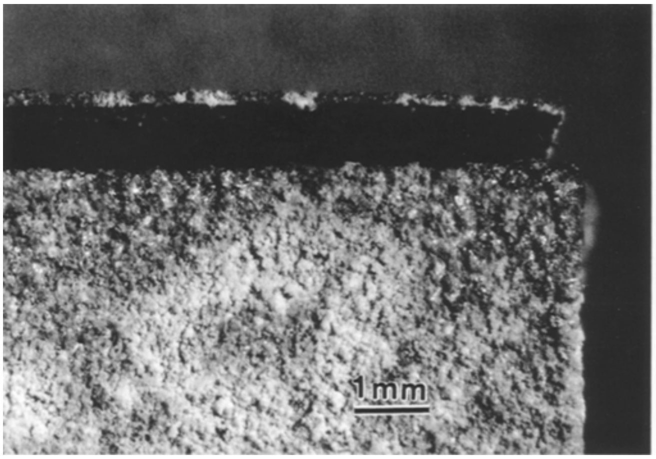

Fig. 1. Exfoliation of Zn/Al (45%/55%) coating layer (thickness 20–30μm) from a corner of a sample after 3 days' oven-drying at 60°C following 12 weeks' exposure to a monoculture of *Trametes versicolor* in the no-choice test

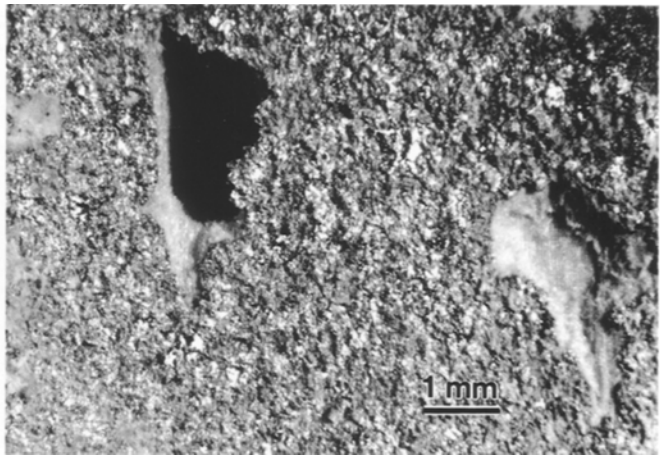

Fig. 2. Invasion of *Coptotermes formosanus* through a 20- to 30-μm coating layer with Zn/Al (45%/55%) after 3 weeks' exposure in the no-choice test

Table 2. Termite resistance of Zn/Al (45%/55%) spray-coated akamatsu sapwood blocks

Condition	Percent mean mass loss (SD)			
	Untreated	A (20–30μm)	B (90–100μm)	C (180–200μm)
Choice test				
Test I (3 weeks)	9.2 (10.13)	0	0	0
Test II (15 weeks)	26.4 (17.23)	NT	1.7 (0.34)	0.7 (0.17)
No-choice test				
JWPA standard	20.9 (4.56)	4.0 (1.52)	0	0

higher treating strengths (B and C) resulted in complete suppression of the decaying activity due to *T. versicolor.*

The mean mass losses of the untreated blocks after 12 weeks' using the no-choice test were 50.3% for *F. palustris* and 25.3% for *T. versicolor*. This shows that the activity of the fungi was in a referable level. The highest mean mass loss of the treated wood blocks in the no-choice test was observed in the case of *T. versicolor*: treatment B (90–100μm thickness)/not-weathered combination, even though the value was only 0.7%. No other cases showed substantial mass losses. Weathering had no effect on the decay resistance of the samples.

Exfoliation of the coating layers was observed after oven-drying at 60°C for 3 days following exposure to the fungal attacks regardless of the treating strength and the type of test (Fig. 1). It usually started from the corners of the samples.

Termite resistance

Table 2 shows the results of the termite tests. In test I the untreated controls showed 9.2% mean mass loss, whereas all of the treated samples showed no mass loss. A prolonged test period resulted in a higher mass loss in test II. After 15 weeks untreated blocks showed more than 26% mean mass loss, and the blocks used for treatments B and C lost their masses at 1.7% and 0.7%, respectively, on average.

After 3 weeks' of forced exposure (no-choice test) to the workers and the soldiers of *C. formosanus*, there was more than 20% mean mass loss of the untreated blocks, which met the requirement of the standard. At the lowest treating strength (A), 4.0% mean mass loss and 8.2% mean mortality (data not shown) were observed. In this case, termites invaded the wood blocks through the coating layers (Fig. 2). The higher treating strengths (B and C) completely protected against termite attacks.

As observed in the decay tests, exfoliation of the coating layers was observed in the termite tests.

Discussion

Spray-coating with Zn-Al prevented fungal attacks in both choice and no-choice situations even at the lowest treating strength of 20–30μm thickness (Table 1). It may have resulted from both the barrier effect of the coating layers and the fungicidal effects of the Zn-Al alloy metal.

Zinc compounds have been evaluated as active agents against decay fungi,[5] and zinc-containing formulations are standardized as wood preservatives in Japanese Industrial Standard (JIS) K-1570-1998. The formulations of $CuSiF_6$ ·

$4H_2O$ – $ZnSiF_6 \cdot 6H_2O$ – $(NH_4)_2Cr_2O_7$ type (CFKZ type: water-borne formulation) or zinc-naphthenate type (emulsified formulation) are available for application of an impregnation treatment at present. Although the toxicity of aluminum to decay fungi has not yet been investigated, the high antimold effectiveness of Zn/Al (50%/50%) spray-coating on paper[6] and plaster board[7] has been compared to that of zinc alone.

Considering the less than 3% mass loss of untreated blocks in the choice test against *T. versicolor*, it is likely that zinc in the coating layer solubilized into a medium and affected the fungal activity because the samples were placed directly on the medium with mycelial mat. This is supported by the facts that there is a lower tolerance of white rot fungi than brown rot fungi to metal-based wood preservatives,[8] and that there was a more than 25% mean mass loss in the untreated blocks at the no-choice test (Table 1).

Workers of *C. formosanus* penetrated the wood through a 20- to 30-μm Zn-Al coating layer. On the other hand, the higher treating strength of more than approximately 100μm thickness resulted in the complete protection against termite invasion. These results suggest that more than 100μm thickness of Zn-Al coating is needed as a termite barrier.

Yamano had evaluated the effectiveness of spray coating with zinc against termites and found that *C. formosanus* and *Reticulitermes speratus* were not able to attack wood blocks spray-coated with 35–70μm thickness in both laboratory and field tests.[9] He extended the work to coating with copper (15% zinc-containing) and aluminum and showed that zinc was the best among the three metals as a termite barrier.[10] Finally, he recommended that more than 50μm thickness was sufficient for antitermite zinc coating. His conclusions agree well with the results of the present investigation.

Exfoliation of the coating layer can be a serious problem in the practical situation. A Zn-Al spray-coating layer is known to be penetrated by water vapor, so wood blocks swell and shrink during the wet-dry process that usually occurs during the outdoor exposure. The present results clearly suggest that an additional vapor barrier treatment should be done to get a long service life of the Zn-Al spray-coating layer on wood and wood-based materials.

Zn-Al spray-coated wood showed excellent resistance against fungi and termite. A coating thickness of 100μm completely prevented fungi and termite invasion. The apparatus for the treatment is movable by car, and the spraying gun can be extended into relatively narrow spaces, even in crawl spaces and inside house walls. Hence remedial (on site) treatment of houses and in the outdoor situation is possible. As a next step, large-scale tests using timber of practical size should be conducted in combination with an investigation of additional vapor barrier treatment.

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