Fifteen-year Test of In-place Treatments for Control of Decay in Waterfront Structures

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1. Introduction

Most waterfront structures are built of wood because of its low initial cost and permanence when properly treated. However, premature failures caused by decay in the above-water portions can occur even though the wood used has been pressure-treated with preservatives (T. L. HIGHLEY and T. C. SCHEFFER, 1978). Decks and large horizontal structural members (curbs, wales) are particularly prone to decay, often developing seasoning checks that expose untreated heartwood. Also, fender piles are frequently damaged by interior decay resulting from infection of untreated heartwood exposed when the pile top is cut to height. The problem is particularly severe with species such as Douglas-fir containing large portions of heartwood, which are difficult to pressure-treat.

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This paper reports the 15-year results of experiments established in 1969 to determine the potential of (a) in-place treatment of deck planking with fungicides for controlling decay in untreated wood or pressure-treated wood having checks that penetrate the zone of preservative treatment and (b) cap and fungicidal treatment for protecting from decay the cut tops of newly installed piles. Earlier papers reported details of the experimental design and observations through 10 years (T. L. HIGHLEY and T. C. SCHEFFER, 1975; T. L. HIGHLEY, 1980).

2. Materials and Methods[2]

2.1 Preparation and treatment of simulated decks and piles

Decks. Fifty simulated decks were constructed in units of conventional untreated deck planks of Douglas-fir (*Pseudotsuga menziesii* Franco) and southern pine (*Pinus* spp.). These are the major species used in waterfront construction. The Douglas-fir was all heartwood which is moderately resistant to decay in aboveground use and the pine was primarily sapwood which has low resistance to decay. There were 25 units of each species, and each contained five 4 x 10 in. planks (T. L. HIGHLEY and T. C. SCHEFFER, 1975; Fig. 1). After 1 year of exposure in southern Mississippi to allow check development, the upper surfaces of the planks were flooded by brush application with formulations of pentachlorophenol (penta) or fluor-chrome-arsenic-phenol (FCAP) (Table 1). The FCAP was applied in a 12% mixture in water (4% actual solution). Three of the five deck planks per unit received annual treatment in years 2 through 9 and two were treated only in the years 2 and 6. Decay in individual planks was rated numerically:

0	No evidence of decay
40	Definite but limited decay
60	Decay general, but not warranting replacement of the item
80	Decay sufficient to warrant replacement of the item
100	Item failed.

Piles. The 80 simulated piles consisted of 2-foot sections cut from piling conventionally pressure-treated with creosote (T. L. HIGHLEY and T. C. SCHEFFER, 1975). The freshly-cut upper ends of groups of 10 sections were given one of seven fungicidal treatments and 10 were untreated (Table 3). To prevent decay from originating at the ground the basal end of all sections was thoroughly flooded with 25% penta concentrate in oil and then coated with a mixture of one part epoxy and three parts rock tan

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Fig. 1. Douglas-fir deck units brush-treated with 5% pentachlorophenol and exposed for 15 years in southern Mississippi.

Table 1: Condition of deck planks treated by flooding the top surface from a brush, after 15 years exposure in Mississippi.

Treating solution and years in which applied	Number of units	Units in decay rating class[1]					Average rating
		0	40	60	80	100	
Douglas-fir							
Sodium penta, 5% (2 through 9)	15	15	0	0	0	0	0
Sodium penta, 5% (2 and 6)	10	7		2	1	0	20
Sodium penta, 5% + WR[2] (2 through 9)	15	15	0	0	0	0	0
Sodium penta, 5% + WR (2 and 6)	10	10	0	0	0	0	0
Penta in mineral spirits, 5% + WR (all treatments)	25	25	0	0	0	0	0
FCAP, 4% (2 through 9)	15	15	0	0	0	0	0
FCAP, 4% (2 and 6)	10	10	0	0	0	0	0
Control	25	0	0	0	8	17	94
Southern pine[3]							
Sodium penta, 5% (all treatments)	25	0	0	0	0	25	100
Sodium penta, 5% + WR (all treatments)	25	0	0	0	0	25	100
FCAP (2 through 9)	15	15	0	0	0	0	0
FCAP (2 and 6)	10	6	1	2	1	0	24
Control	25	0	0	0	0	25	100

[1] On a scale of zero to 100, a rating of 80 indicates sufficient decay to warrant replacement of a plank.
[2] WR = water repellent.
[3] The penta-treated and untreated southern pine planks failed by the 7th year.

(Detroit Graphite Co.). The pile sections were placed upright with the basal ends contacting the ground. A cap of "Noah's Pitch" (Philip Carey Co.) was applied to 7 of the 10 section tops in each group following treatment. The other three tops were not capped to determine what might happen if damaged caps were not repaired. The untreated control sections consisted of seven uncapped and three capped section tops. The fungicides used and the method of application are given in table 3.

Deck units and pile sections were exposed in the open at the Forest Service National Exposure Site near Gulfport, Miss., where the combination of temperature and rainfall is highly favorable to decay (T. C. SCHEFFER, 1972). Surface decay was observed by probing with a pick. Interior decay was judged from the condition of increment borings and by culturing portions for decay fungi.

2.2 Residual penta and FCAP in deck planks

Residual penta or FCAP in deck planks was detected in the outer eighth inch of wood, chemically by the American Wood-Preservers' Association method (AWPA, 1983) or by bioassaying for the fungus-inhibiting chemical with *Gloeophyllum trabeum* (Pers. ex Fr.) Murr. Samples were collected by removing surface chips, approximately 1-inch square, using a chisel.

For chemical analysis, samples were reduced in a Wiley mill to pass a 1-mm screen. Retention of fluor-chrome- arsenic-phenol (FCAP) was determined by chemical analysis for arsenic and chromium and from these data the fluoride and dinitrophenol were calculated according to the formulation for FCAP in the AWPA manual (1983). Total salt concentrations were determined from the amounts of fluoride and dinitrophenol.

Bioassays were conducted by placing chips in 90-mm petri dishes near the edge on a malt-agar (2% malt extract, 1.5% agar) nutrient medium inoculated in the center with *G. trabeum* (T. C. SCHEFFER and R. O. GRAHAM, 1973). The plates were incubated at 27 °C and 80% relative humidity. Zones of growth inhibition were measured when the fungus in the control plates without treated wood had covered the agar surface.

3. Results and Discussion

Condition of Brush-Treated Decks. The condition of the deck planks after 15 years of exposure is given in table 1. The three penta formulations and the FCAP mixture, brushed on the upper surface of the Douglas-fir decking in years 2 and 6 or 2 through 9 after construction, continue to offer excellent protection. The only decay detected was in a few planks that had only been treated with sodium penta in the 2nd and 6th year. This decay was first observed after 12 years. Flooding the upper surfaces of southern pine units with the penta formulations provided essentially no protection; both treated and untreated planks were significantly decayed after 3 years, and failed at the end of 7 years. However, much better results were obtained with FCAP on the pine units. With this preservative. annual flooding in years 2 through 9 has prevented decay in southern pine

for 15 years. Flooding in years 2 and 6 also provided good protection, but some of the pine planks decayed after 10 years of exposure.

It is evident from this study and others (T. C. SCHEFFER and W. E. ESLYN, 1978,1982) that simple in-place treatments with a preservative can add substantially to the service life of Douglas-fir exposed out of ground contact (T. C. SCHEFFER and W. E. ESLYN, 1978,1982). The southern pine sapwood is relatively susceptible to decay, and more difficult to protect by in-place treatments. In a study by T. C. SCHEFFER et al. (1963, 1971, 1982), pine flooring panels dipped in penta and exposed in Mississippi were protected from decay for up to 7 years but were substantially decayed at 15 years and nearly 100% failed at 22 years. Penta-treated Douglas-fir flooring panels exposed through the same period were essentially decay free at 15 years and had only slight to moderate decay at 22 years. We found an upper surface treatment with penta gave similar protection of Douglas-fir heartwood deck planking, but afforded no protection to pine sapwood planking. The excellent response of Douglas-fir to simple in-place treatments must be attributed to its natural decay resistance coupled with the treatments used (T. C. SCHEFFER and W. E. ESLYN, 1982). The superiority of FCAP over penta in protecting the pine planks may mean FCAP is more able to protect vulnerable weather checks, initially by penetrating the wood deeper, and subsequently by movement of residual preservatives from near the surface into checks as they form. We (T. L. HIGHLEY and T. C. SCHEFFER, 1978) also observed FCAP gave superior protection of checks in large sawed timbers having only shallow treatment.

FCAP is no longer produced in the United States and environmental concerns are limiting the use of penta. However, the relative effectiveness of these treatments probably would not be greatly altered if fungicides having comparable preservative properties were used in their place. An essential requirement of preservatives considered for in-place treatment of large structural members, such as those used in waterfront construction, is the ability to migrate into weather checks as they form. The excellent success with FCAP suggests that waterborne preservatives meet this requirement best and therefore should be considered for this use in future research.

In-place brush treatments can be recommended only as decay preventives and not as eradicants of established decay. We found these brush treatments ineffective in controlling decay already established in checks of large, horizontal Douglas-fir members (T. L. HIGHLEY and T. C. SCHEFFER, 1978). If decay is evident from probing or boring, it has probably progressed too far to be controlled by a brush or spray treatment.

Residual Penta and FCAP. The absence of decay in Douglas-fir deck planks treated with penta and FCAP and southern pine treated with FCAP suggested that residual preservatives remained in decay inhibiting

amounts after 15 years of exposure. Bioassays of chip samples confirm the presence of residual penta in Douglas-fir planks that received treatment with one of the three penta formulations in years of exposure 2 through 9 (Table 2). The bioassay also showed penta to be present in Douglas-fir

Table 2: Bioassay and chemical analysis of residual penta and FCAP in surface wood of Douglas-fir and southern pine deck planks after 15 years.

Deck treatment	Treatment in years 2 through 9		Treatment in years 2 and 6 only	
	Inhibition[1]	Retention, pcf	Inhibition[1]	Retention, pcf
Douglas-fir				
Sodium penta, 5%	+	.04	0	.01
Sodium penta, 5% + WR[2]	+	.05	0	.03
Penta in mineral spirits, 5% + WR	+	.10	+	.04
FCAP, 4%	0	.31	0	.19
Southern pine				
FCAP, 4%	0	3.83	0	0.92

[1] Inhibition: No fungus inhibition, 0; fungus able to reach wood but unable to grow on it, +; fungus unable to reach wood, ++.
[2] WR = water repellent.

Table 3: Numbers of decayed and sound sections of treated Douglas-fir pile cutoff tops after 15 years.

Treatments[1]	Capped tops		Uncapped tops	
	Sound	Decayed	Sound	Decayed
Ammonium bifluoride in holes 1 in. diameter, 2 in. deep	7	0	3	0
Ammonium bifluoride in holes 2 in. diameter, 1 in. deep	7	0	3	0
Penta grease	7	0	3	0
Penta (12.5%) in No. 2 fuel oil in holes 1 in. diameter, 2 in. deep	7	0	0	3
Penta (12.5%) in No. 2 fuel oil in holes 2 in. diameter, 1 in. deep	7	0	1	2
Penta (12.5%) and water repellents	6	[2]1	0	3
Penta (25%), no water repellents	6	1	0	3
No preservative, controls	1	[3]2	0	7

[1] To reduce loss of volatile oil carrying the penta, penta-grease containing 10% penta was troweled on and then covered with a sheet of 6-mil polyethylene for 48 hours. The penta solutions not applied in holes were flooded onto the pile top. An asphalt preparation was used for capping.
[2] Cap broken.
[3] One pile with visual decay. One pile decay fungi isolated but wood without obvious decay.

planks treated only in the 2nd and 6th year with water repellent pentachlorophenol. Chip bioassays showed no inhibition (or evidence of residual preservative) either in Douglas-fir planks treated only in the 2nd and 6th year with sodium penta or in planks of either Douglas-fir or southern pine treated with FCAP. The corresponding chemical analysis (Table 2) showed very small amounts of residual penta in the Douglas-fir planking, but substantial amounts of FCAP in both species. As would be expected, concentrations were higher in planks treated annually for 8 years than in those treated only twice.

The bioassays indicated the presence of penta in all cases in which the amount detected by the chemical analysis was 0.04 pcf or more (Table 2). Similarly, previous chemical and fungus assays by T. C. SCHEFFER and W. E. ESLYN (1978) both detected small amounts of penta in panels of flooring that had been dip-treated 22 years earlier. Our bioassays for FCAP were all negative despite the high amounts indicated by chemical analysis. Only two components of FCAP, chromium and arsenic, were analyzed. Possibly the components were too tightly held to diffuse into the agar and cause inhibition zones. Also, the fluoride and dinitrophenol may have leached from the wood surface. R. H. BAECHLER (1953) found fluoride to be much more leachable than arsenic and chromium from FCAP treated wood. No data were available on the leachability of dinitrophenol. Another factor may be arsenic tolerance of *G. trabeum;* R. H. BAECHLER (1953) found that this fungus attacked leached blocks treated with FCAP about as severely as untreated controls.

Pile top treatments. The 15-year results of pile top treatments differ very little from those reported after 10 years (T. L. HIGHLEY, 1980). All fungicidal treatments in combination with an intact cap continued to offer good protection against decay. Only ammonium bifluoride crystals applied in holes and penta-grease continued to protect uncapped pile sections from decay. Considerable protection was obtained by capping without a fungicide, but we do not recommend this because of possible exposure of untreated wood to infection following checking or cracks in the capping material.

We reported previously (T. L. **HIGHLEY,** 1980) that decay fungi had been isolated from uncapped pile sections treated with penta-grease although the wood appeared sound. The fungi must have been transitory as none appeared in subsequent isolations and at 15 years the wood is still visually sound. The penta-grease formed a protective seal on the pile tops that minimized checking, and this probably contributed to its better performance than the other penta treatments on uncapped piles. Another consideration is that better penetration of the penta was obtained with the penta-grease treatment because the wood was exposed to the penta and carrying

oil longer than to the other treatments by virtue of the thick application and its cover of polyethylene for 48 hours to reduce loss of volatile oil.

4. Conclusions

Information from this study and others (G. G. HELSING and R. D. GRAHAM, 1980; T. L. HIGHLEY, 1984a) indicate that the easiest and most effective fungicidal treatments for pile cutoffs are fluoride-containing waterborne preservatives. Speculation concerning reasons for their excellent performance has been discussed in previous papers (T. L. HIGHLEY, 1984a, b). Recently, T. L. HIGHLEY (1984a) showed that ammonium bifluoride, merely brushed on to the pile tops, can be effective against decay for at least 5 years. Additional observation is necessary to determine whether or not brush treatment with ammonium bifluoride will protect as long as the treatment with crystals applied in holes reported here. Although Douglas-fir pile tops can be protected from decay by fungicidal treatment without a cap, a water-shedding cap in combination with a proven preservative (preferably waterborne) is recommended. The cap prevents excessive checking and the preservative eliminates any incipient decay that may have been established.

Untreated Douglas-fir planking was protected from decay for 15 years in southern Mississippi by brush application of penta, sodium penta, or FCAP only to the top surface either in years 2 and 6 or in years 2 through 9. Southern pine planking was protected only by FCAP.

5. Summary

Brush application of pentachlorophenol, sodium pentachlorophenate or fluor-chrome-arsenic-phenol (FCAP) to the top surface of untreated Douglas-fir deck planks (in years 2 and 6 or 2 through 9) has protected against decay for 15 years in the high-decay-hazard climate of southern Mississippi. However, only application of FCAP protected southern pine planking under the same conditions. Protection against decay fungi entering the cutoff ends of creosoted Douglas-fir piling was obtained using penta solutions, penta-grease, and ammonium bifluoride applied to the freshly exposed tops and covered by an asphaltic cap. Without a cap, only ammonium bifluoride in holes or troweled-on penta-grease prevented decay for as long as 15 years.

Zusammenfassung

Fünfzehnjährige Untersuchungen von in situ-Behandlungen zur Bekämpfung von Pilzbefall in Wasserbauten

Deckplanken aus Douglasie konnten durch eine Oberflächenbehandlung im Anstrichverfahren (im 2. und 6. Jahr oder vom 2. bis zum 9. Jahr) mit Pentachlorphenol, Natriumpentachlorphenolat oder Fluor-Chrom-Arsen-Phenol (FCAP) während

der 15jährigen Versuchsdauer in dem für den Pilzangriff sehr förderlichen Klima von Süd-Mississippi vor dem Abbau durch holzzerstörende Pilze geschützt werden. Beplankungen aus Southern pine wurden unter den gleichen Bedingungen nur durch Behandlung mit FCAP geschützt. Ein Schutz der Hirnfläche von Steinkohlenteeröl-getrankten Douglasien-Pfählen gegen das Eindringen holzzerstörender Pilze wurde erreicht durch deren Behandlung in frischem Zustand mit Pentachlorphenollosungen, PCP-Fettgemisch und Ammoniumbifluorid und anschließende Abdeckung mit einer Asphaltkappe. Ohne Kappe verhinderten nur Ammoniumbifluorid in Bohrlöchern oder dick aufgetragenes Pentachlorphenolfett einen Pilzbefall fur die Dauer von 15 Jahren.

Résumé

Essai sur 15 ans de traitement in situ contre des attaques de champignons sur des constructions aquatiques

Sur de planchers de pont non traités, des applications par badigeonnage sur toutes les faces du bois ont été réalisées au cours de la seconde, puis de la sixième année après la mise en service ou de la seconde à la neuvième année à l'aide de pentachlorophenol, de pentachlorophénolate de soude ou de FCAP (fluor-chrome-arsenic-phenol) et ont protege le bois durant 15 ans contre la pourriture sous le climat du sud Mississippi. Dans les mêmes conditions des planchers de pont en southern pine ont été traités en une seule application de FCAP. La protection des surfaces des bouts de poteaux en Douglas, imprégnés de creosote, a été obtenue pour application, à l'état frais, de solutions de pentachlorophenol, de graisse de pentachlorophenol et de biofluorure d'ammonium, complete par un couvercle d'asphalte. Sans ce couvercle, seul le bifluorure d'ammonium mis en place dans des perforations, ou une couche épaisse de graisse de PCP ont apporté une protection de 15 ans de ces bouts.

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