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Response of Marine Borers to Chemically Treated Woods and other Products

By CHARLES HOWARD EDMONDSON
BERNICE P. BISHOP MUSEUM

INTRODUCTION

The reinforcement of natural woods against decay by fungi and destruction by insects while in contact with air or soil is fast becoming a major industry. New fungicides and insecticides in various combinations for the chemical treatment of wood have been developed in recent years at a rapid rate. Some are adapted for the impregnation of wood, others for external application; many of them, doubtless, have considerable merit.

Transmuted woods and synthetic products, including plastics, are also entering more and more into modern economy. Many of these are thus far adapted for rather limited or special purposes, but durability and prolonged resistance to agents of destruction are important factors.

The chemical impregnation of wood has even extended to the injection of preservatives into living trees with a view to increasing their resistance to decay and improving their durability for later use in contact with the soil. Wilford (15)[1] reviews the history of this process, points out some of its advantages and disadvantages, and gives a list of satisfactory or promising chemicals.

The preservation of wood when in contact with sea water, however, is quite a different undertaking from its preservation when in contact with air or soil. Consideration must be given to the powerful leaching property of salt water, which is capable of rapidly dissipat-

[1] Numbers in parentheses refer to Literature Cited, page 133.

ing many chemical compounds either applied externally or injected into the wood. Another factor is the erosive action of sea water which gradually wears away surface coatings and reduces the protective qualities of preservatives. Especially is this true in situations where there is a free circulation of water.

The chief destructive agents of wood in the sea are representatives of the molluscan and crustacean groups of animals collectively known as marine borers. The principal molluscan borers are teredinids, such as *Teredo* and *Bankia,* called shipworms, and the pholad *Martesia.* Among the destructive crustaceans are *Limnoria,* known as the gribble, and *Chelura* and *Sphaeroma.* Because of their more limited distribution, *Chelura* and *Sphaeroma* are usually of less importance than the gribble.

The gribble frequently is a more serious menace than the shipworm, although the two often supplement each other in their destructive action. Unlike shipworms, the gribble works superficially, and the wood gradually sloughs off until the entire section may be destroyed. The penetration of a chemical compound into wood, even under pressure, is usually relatively shallow; and should the treated surface remain susceptible to the gribble, the superficial protective layers may soon be lost, opening up channels of attack by the shipworms.

A correlation between the activity of termites and that of shipworms (teredos), although somewhat comparable as to results, becomes obscure when methods of destruction and conditions of operation are considered. Little is known of the actual toxic effect upon marine borers of many of the chemical compounds devised for the inhibition of insect pests or the prevention of decay. Toxic agents potent enough to destroy or repugnant enough to repel termites give little assurance that they will react in a similar way when operating against marine wood borers. Furthermore, the problem of varied response between molluscan and crustacean borers should not be overlooked. Chemical compounds which apparently check the action of one group of marine borers may have little retarding effect upon the other. This is illustrated in the numerous tests recorded below, wherein either the teredo or the gribble was inhibited, perhaps only briefly but nevertheless appreciably, whereas the activity of the other was unaffected.

Although in recent years many investigators have sought to prolong the durability of wood by chemical or other means, comparatively few of these attempts have had security against marine borers as the sole or primary object. The need for better protection of wood installations in bays and harbors and for prolonging the life of small boats, however, has stimulated renewed interest in this direction. Bryan (3), in the nineteenth report of the Institution of Civil Engineers of Great Britain, reviews the results of experimental work on the response of marine borers to numerous toxic substances, either used separately or added to creosote. MacLean (7) presents results of extensive tests of treated timbers at Gulfport, Mississippi, and Pensacola, Florida, the last inspection having been made in December 1946. Shoemaker (9) has suggested certain chemical applications to protect the wooden hulls of small naval vessels against borer attack; and, from time to time, results of chemically treated wood exposed to marine borers have been reported from the Marine Laboratory of the University of Miami. (See Smith, 10, 11.)

Since the effect of preservatives on the larvae of marine wood borers is highly important, significant studies on leaching are being made at the Miami Laboratory. Objects of the investigations include the determination of the time required to immobilize larvae when placed in close contact with treated wood and the general reduction of protection against borers by leaching. (See Smith, 11-13.)

This paper records the response of marine borers to certain chemically treated woods and other products, some of which show remarkable resistance to termites but have not, until now, been examined for their reaction to marine borers.

Some of the treated woods and wood products were supplied by and examined at the request of the producing companies; others, well-known commercial products, were procured through such manufacturers. Other wood samples were processed by the Yard Testing Laboratory (United States Navy), Pearl Harbor, where valuable chemical observations were made also. The United States Naval Civil Engineering Laboratory, Solomons, Maryland, and the Monsanto Chemical Company, Saint Louis, Missouri, furnished wood samples treated according to special formulae. Arboneeld wood products were supplied by du Pont de Nemours and Company, Wilmington, Delaware, who also processed numerous Hawaiian-grown woods for testing purposes. The Koppers Company, Orrville, Ohio, provided samples of Asidbar for examination. And specimens of Synthane plastic were received from Synthane Corporation, Oaks, Pennsylvania.

Examples of creosoted wood (*Sassafras* sp.), impregnated under pressure, were received from the Maritime Services Board, Sydney, Australia. Industrial companies, such as Nuodex Company, Elizabeth, New Jersey; the Dow Chemical Company, Midland, Michigan; the Monsanto Chemical Company, Saint Louis, Missouri; and the M. Gurvey Company, Toronto, Canada, were very generous in supplying special products with which woods were treated in our own laboratories. Other chemical compounds utilized for a similar purpose were procured through commercial channels.

Through the courtesy of Dr. George N. Wolcott of the Agricultural Experiment Station, University of Puerto Rico, I was given the opportunity to note the effect of numerous chemical compounds on the action of marine borers, compounds which had previously been checked by Dr. Wolcott during his extensive work on termite control.

The processing of the test blocks followed several methods. Some were painted with two coats of the preserving solution applied by brush, the sample being completely dried between coats and before submergence. The immersion, or dipping, process was also used, the sections of wood being immersed in the solution, without pressure, for varied intervals ranging from one minute to 48 hours. Some of the products examined, especially those of commercial usage, were treated under pressure by the producing companies, thereby impregnating the wood with a controlled amount of the preserving solution. Other special or transmuted products examined were developed by the producers under special techniques.

The intervals of submergence of many of the chemically treated test blocks were purposely short in order to detect, if possible, some influence of the preserving fluid before it might become dissipated by the action of sea water. Experience has shown that susceptible woods in Hawaiian waters are badly damaged by marine borers in two or three months. Short intervals of submergence compared with longer ones, as was done in many of the experiments, also gave some indication of the rapidity of the leaching process by which the toxic solution was rendered ineffective.

TREATED WOODS AND OTHER PRODUCTS

Wolmanized Wood

The object of the Wolman process is to repell decay while the wood is in contact with air and soil and, especially, to reduce its vulnerability to termites. Preservatives serving as resistant factors by which the wood is impregnated consist of two groups: (1) Triolith—composed of sodium fluoride, dinithrophenol, and chromates—to counteract decay; (2) Tanalith—the composition of Triolith with arsenate added—to counteract decay and insect attack. The chromates may serve to reduce leaching.

Wolmanized wood is widely used in the building trade, and extensive tests and experience apparently justify its reputation for resisting decay and destructive insects. To determine whether it is durable under marine conditions and to evaluate the advantage, if any, of the treated wood when in contact with sea water, test blocks of treated Douglas fir, together with controls, were installed at a number of stations about Oahu. Cut ends of treated blocks were protected by borer-resistant antifouling paint. Following are the results of the experiments:

a. Kaneohe Bay: Blocks submerged for 123 days. Moderate damage by teredos; action by the gribble light. Controls moderately damaged by teredos and the gribble.

b. Hanauma Bay: Blocks submerged for 87 days. Moderate damage by teredos, maximum penetration 105 mm.; action by the gribble light. Controls badly damaged by teredos and the gribble. Blocks submerged for 125 days gave the same results.

c. Pearl Harbor: Blocks submerged for 70 days. Moderate damage by teredos; action by the gribble light. Controls badly damaged by teredos and the gribble.

d. Waikiki: Blocks submerged for 113 days. Heavy attack by teredos; maximum penetration 140 mm.; action by the gribble light. Controls badly damaged by teredos and the gribble.

e. Honolulu Harbor: Blocks submerged for 182 days (fig. 1, *a*). Badly damaged by teredos and the gribble. Controls riddled by teredos and the gribble (fig. 1, *b*). Blocks submerged for 288 days were heavily damaged by teredos and the gribble. Controls as for 182 days.

The tests show that attacks on Wolmanized wood by marine borers were consistently made at all stations at all intervals, the heavier damage resulting from longer periods of submergence. During the shorter intervals of two or three months destruction of treated blocks amounted to about 50 percent of that of untreated controls. This apparent advantage, however, was eliminated after about four months. It is obvious that the Wolman treatment is of little value in prolonging the durability of Douglas fir in sea water.

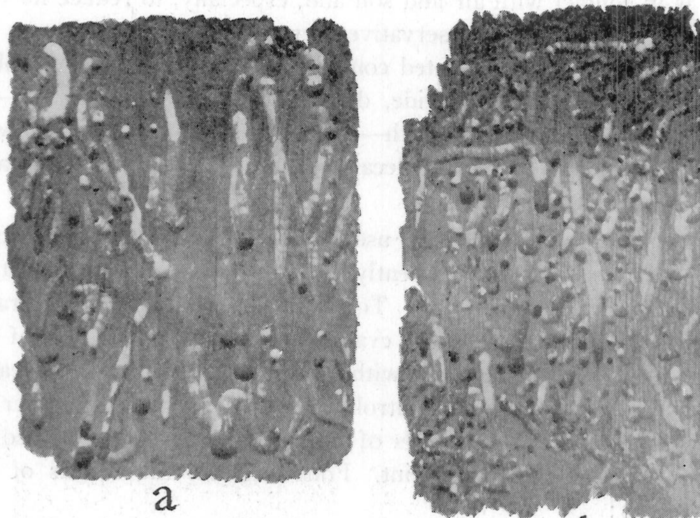


FIGURE 1.—a, Wolmanized wood, submerged for 182 days; b, control of *a*.

CHEMONITE TREATMENT

The Chemonite treatment of wood, which consists of full-cell pressure of a solution including copper and arsenic salts and ammonium acetate, was developed at the University of California nearly 30 years ago. During the past 10 years the West Oregon Lumber Company of Portland, Oregon, has been one of the larger producers of Chemonite lumber. This treatment has several advantages. It does not require pre-seasoning of wood; it hardens the wood slightly, with no loss of strength; the nail holding power is increased, and the surface holds paint well; it retards decay by fungi and is highly toxic to termites.

Samples of treated wood processed by the West Oregon Lumber Company and obtained through Honolulu dealers were tested in Honolulu Harbor for their durability in sea water. The treatment of these

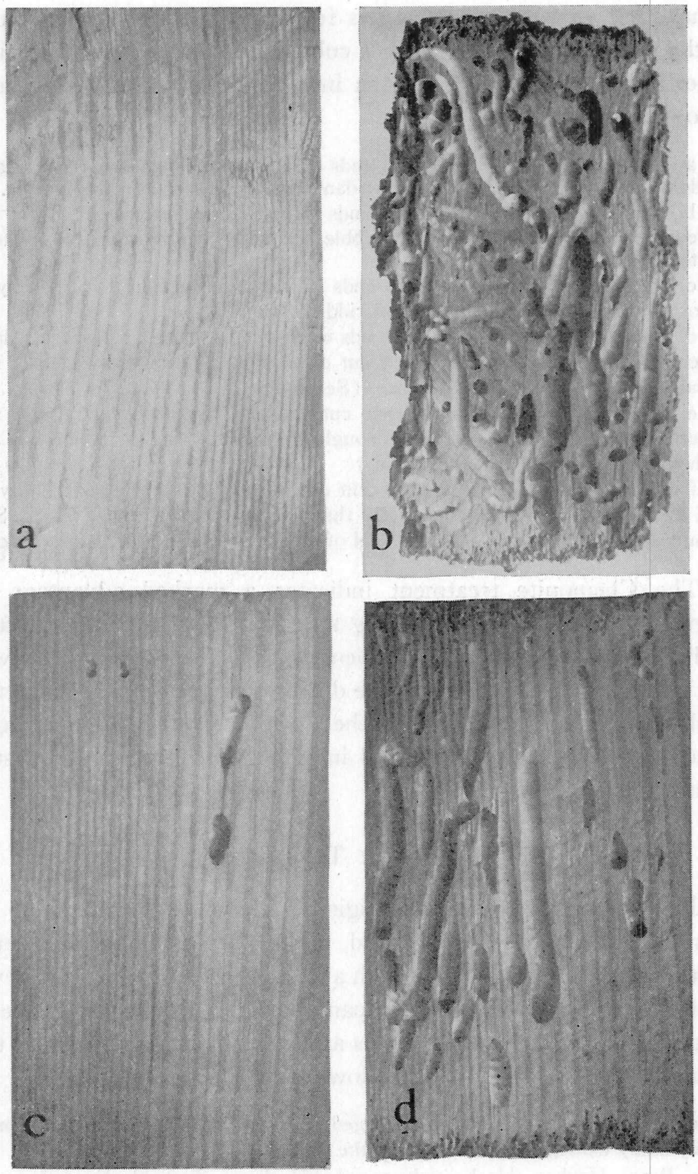


FIGURE 2.—Chemonite treatment: **a,** both cut ends protected, submerged for 195 days; **b,** control of *a;* **c,** one end protected, submerged for 14 months; **d,** ends not protected, submerged for one year.

samples is believed, according to information from C. W. Ott (8), to have followed the specifications for a minimum retention of three-tenths pound of preservative per cubic foot of wood and a minimum penetration of three-eighths inch into the wood. The results are as follows:

a. Submerged for 112 days, cut ends of test blocks protected: No attack by teredos or the gribble. Controls badly damaged by teredos and the gribble.

b. Submerged for 154 days, cut ends of test blocks protected: Light attack by few teredos; no action by the gribble. Controls heavily attacked by teredos and the gribble.

c. Submerged for 195 days, cut ends of block protected: No attack by teredos or the gribble (fig. 2, *a*). Control riddled (fig. 2, *b*).

d. Submerged for one year, cut ends of block unprotected: Moderate damage by teredos, entrance wholly through cut ends of block; action by gribble severe at ends, very light on treated surface. (See figure 2, *d.*)

e. Submerged for 14 months, one cut end of block protected: Light attack by teredos, with entrance wholly through unprotected end of block; no action by the gribble noted. (See figure 2, *c.*)

f. Submerged for 17 months, one cut end of test block protected: Badly damaged by teredos, with entrance wholly through unprotected end of block. Severe action by the gribble at unprotected end of block; no trace on treated surface.

The Chemonite treatment indicates a marked advantage over untreated Douglas fir in repelling marine borers. During the course of the observations few teredos penetrated the treated surface, which was lightly attacked by the gribble during some of the longer intervals. With thorough, even treatment, the Chemonite process gives promise of converting a susceptible wood into one of considerable resistance to marine borers.

Permasan Treatment

The Permasan treatment (originally known as Permatol-A) consists of the impregnation of wood, under pressure, by a five percent solution of pentachlorophenol with a fluid oil solvent, a process devised by the Monsanto Chemical Company of Saint Louis. By request of the company, processed test blocks and controls were installed at three stations about Oahu, with the following results:

a. Hanauma Bay, blocks submerged 153 days: Test blocks and controls equally badly damaged by teredos and the gribble.

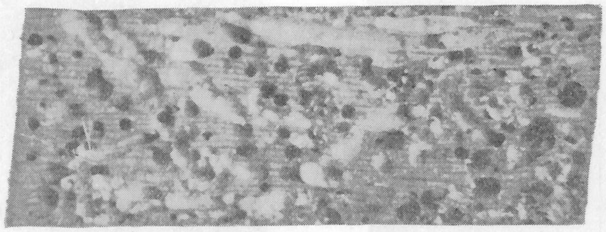
b. Pearl Harbor, blocks submerged 153 days: Test blocks and controls equally badly damaged by teredos and the gribble.

c. Waikiki, blocks submerged 138 days: Test blocks and controls equally badly damaged by teredos and the gribble. (See figure 3, *a, b.*)

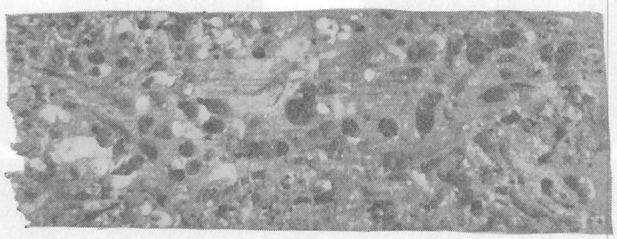
Additional tests were made with test blocks processed by immersion in Permasan solution, with the following results:

a. Blocks immersed in solution 10 minutes, then submerged in Honolulu Harbor for 138 days: Riddled by teredos and the gribble.

b. Blocks immersed in solution for 24 hours, then submerged for 168 days: Riddled by teredos and the gribble.



a



b

FIGURE 3.—a, Permasan treatment applied under pressure, submerged for 138 days; b, control of *a*.

The Permasan treatment, whether applied with or without pressure, apparently has little or no influence in checking the action of marine wood borers. In the above tests, treated blocks were equally damaged or riddled with untreated controls. In the immersion process, contact with the solution for 24 hours gave no more protection than the contact for 10 minutes.

ARBONEELD PRODUCT

The Arboneeld product, developed by du Pont de Nemours and Company, consists of wood impregnated under pressure by water insoluble methylolurea at high temperature, the chemical reaction producing a hardening process. Although the treating solution may vary somewhat in proportion of ingredients, the following may be con-

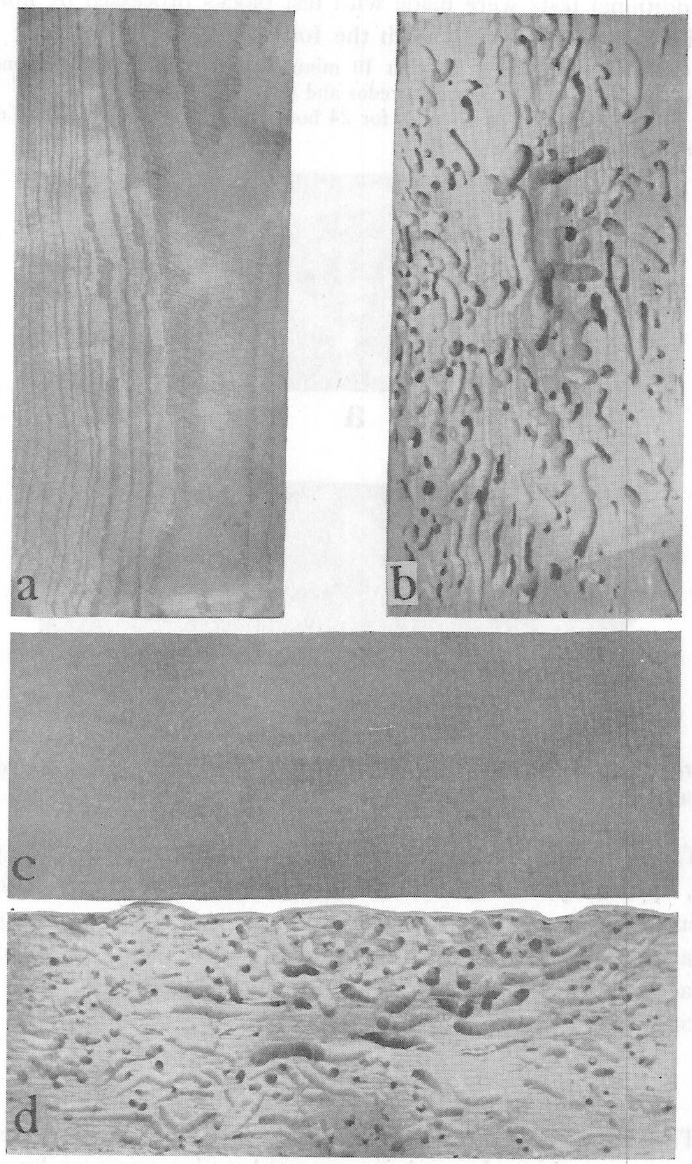


FIGURE 4.—Southern cypress: **a**, methylolurea 63 percent, submerged for 280 days; **b**, control of *a;* **c**, methylolurea 59 percent, submerged for one year; **d**, control of *c*.

sidered standard procedure: urea 6.5 percent, dimethylolurea 26.1 percent, water 67.4 percent; all parts by weight. The total solids in such a solution would amount to about 30 percent. A small amount of insoluble resin which is suspended in the solution filters out on the surface of the wood during the treatment, which was not developed specifically as a preservative of wood but as a hardening process for soft woods, with the resulting advantages which may follow such a transmutation.

The process is suitable only for woods that can be fully impregnated by the solution, the absorption of which depends upon a number of factors. The excessive density of some woods prevents impregnation with an effective amount of the solution, hence sapwood is usually more easily treated than heartwood. The absorption of the solution depends also upon the *p*H of the wood.

Douglas fir cannot be fully impregnated and, therefore, is not a suitable wood for processing. California redwood is apparently on the border line, its absorbing properties varying greatly. Some examples of redwood can be fully impregnated, whereas others do not readily take the solution. The sapwood of certain pines and of the southern cypress, *Taxodium distichum,* are especially suitable for processing by this method.

Through the cooperation of the Chemical Division of du Pont de Nemours and Company extensive tests of the Arboneeld product were carried out in Hawaii to determine the durability of this transmuted wood in sea water and its reaction to marine borers. Test blocks treated by the company were installed in Honolulu Harbor, along with controls. The character and results of the observations follow:

SOUTHERN CYPRESS

a. Sapwood blocks (methylolurea content 63 percent) and controls submerged for 184 days: Treated blocks showed no infestation by marine borers; whereas controls, both sapwood and heartwood, were badly damaged by teredos and the gribble. Of the controls, damage to heartwood was slightly less than to sapwood by teredos and somewhat greater by the gribble.

b. Sapwood blocks (methylolurea content 63 percent) and controls submerged for 280 days: No infestation of treated blocks (fig. 4, *a*); controls badly damaged (fig. 4, *b*).

c. Sapwood blocks (methylolurea content 59 percent) and controls submerged for one year: No attack by marine borers (fig. 4, *c*); controls, both sapwood and heartwood, heavily damaged (fig. 4, *d*).

CALIFORNIA REDWOOD

a. Heartwood blocks (methylolurea content 59 percent) and controls submerged for one year: No infestation of treated blocks; controls badly damaged by both teredos and the gribble.

b. Heartwood blocks (methylolurea content 63 percent) and controls submerged for one year: No infestation of treated blocks (fig. 5, *a*); controls badly damaged by teredos and the gribble (fig. 5, *b*).

c. Heartwood blocks (methylolurea content 61 percent) and controls submerged for one year and nine months: Treated blocks lightly attacked by teredos (two small specimens); no action by the gribble. Controls badly damaged by teredos and the gribble.

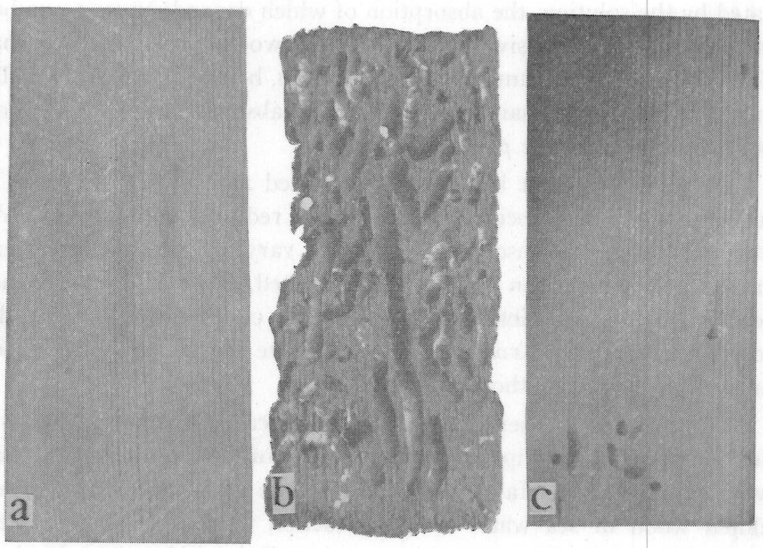


FIGURE 5.—Redwood: **a**, methylolurea 63 percent, submerged for one year; **b**, control of *a*; **c**, methylolurea 63 percent, submerged for two years and six months.

d. Heartwood blocks (methylolurea content 63 percent) and controls submerged for two years and one month: Treated blocks without attack, but controls riddled by teredos and the gribble.

e. Heartwood blocks (methylolurea content 63 percent) and controls submerged for two years and six months: Treated blocks lightly attacked by teredos; action by the gribble slight (fig. 5, *c*). Controls riddled.

LOBLOLLY PINE

a. Sapwood blocks (methylolurea content 39 percent) and controls submerged for 150 days: Treated blocks without attack by teredos; moderate damage by the gribble. Controls destroyed to the extent of 45 percent.

b. Sapwood blocks (methylolurea content 56 percent) and controls submerged for 150 days: Treated blocks lightly attacked by teredos, maximum penetration 10 mm.; moderate attack by the gribble. Controls destroyed to the extent of 45 percent.

c. Sapwood blocks (methylolurea content 40 percent) and controls submerged for 176 days: Treated blocks lightly attacked by teredos, maximum penetration 65 mm.; slight action by the gribble. Controls badly damaged, especially by the gribble.

PROCESSED HAWAIIAN-GROWN WOODS

Sections of 15 species of Hawaiian-grown woods, selected at random without reference to relative amounts of sapwood and heartwood or degree of seasoning, were processed at the Chemical Laboratories of du Pont de Nemours and Company and installed in Honolulu Harbor with controls. The purpose was to determine the advantage, if any, which treated sections might have over untreated controls in respect to their resistance to marine borers. Examination was made after submergence for eight months. Table 1 records the species of woods, the methylolurea content possible during processing, the reaction to marine borers (teredos and the gribble combined), and the estimated advantage, if any, over untreated controls.

Table 1

Species	Methylolurea content (percent)	Results	Evaluation
Acacia koa	22	riddled	no advantage
Achras sapota	1	light attack	some advantage
Calophyllum inophyllum	15	heavy attack	no advantage
Colubrina oppositifolia	7	light attack	some advantage
Cunninghamia lanceolata	30	light attack	much advantage
Eucalyptus robusta	26	riddled	no advantage
Eugenia aquea	29	moderate attack	some advantage
Ficus indica	37	light attack	much advantage
Hibiscus tiliaceous*	90	no attack	control lost
Metrosideros collina subsp. polymorpha	8	light attack	some advantage
Rhizophora mangle	15	riddled	no advantage
Samanea saman	18	heavy attack	no advantage
Thespesia populnea	32	riddled	no advantage
Toona febrifuga	48	light attack	much advantage
Tristania conferta	21	light attack	some advantage

* Previous tests show this natural wood to have little resistance against marine borers.

Regarding the treated sections of the Hawaiian-grown woods listed in table 1, there are such undetermined data as the relative proportion of sapwood and heartwood, the *p*H, the density, the degree of seasoning, and so forth, which may have bearing on the results. It is significant, however, that those species having a low degree of absorption of the treating solution are among the harder of Hawaiian woods. It may also be significant that the species indicating considerable advantage over controls are, for the most part, those capable of fuller impregnation than others. From the data, it is apparent that the harder woods need absorb but small amounts of the solution to gain some advantage over untreated controls.

Since the Arboneeld product was not developed with a view to increased protection against decay or deterioration under severe conditions, the specific explanation for its resistance to agents of destruction is not altogether clear. The observations of Stamm and Seborg (14), however, indicate that the treatment of wood with synthetic resins greatly increases its resistance to decay, and these investigators suggest that the resistance is probably due to the incapacity of resin-coated cell walls to absorb enough moisture to support decay. Kvalnes (5) of the Chemical Division of du Pont de Nemours and Company points out that there should be substantially no loss of resin from the methylolurea-treated wood due to leaching; and he concludes that the dry fiber effect may explain, in part at least, the resistance of the Arboneeld product, adding that the increased hardness of the wood may also be a factor.

Impreg and Compreg

Resin-treated wood products known as Impreg and Compreg were developed by the Forest Products Laboratory, Madison, Wisconsin. The impregnation of wood with synthetic resin-forming chemicals gives stability against swelling and shrinking. Resin-forming elements penetrate the cell-wall structure and become bonded to the active groups of the wood upon formation of the resin. Impreg is veneered wood impregnated with a resin solution which is cured under high temperature. Compreg is laminated, the veneers impregnated with resin and the structure formed into a solid mass under high temperature and great pressure.

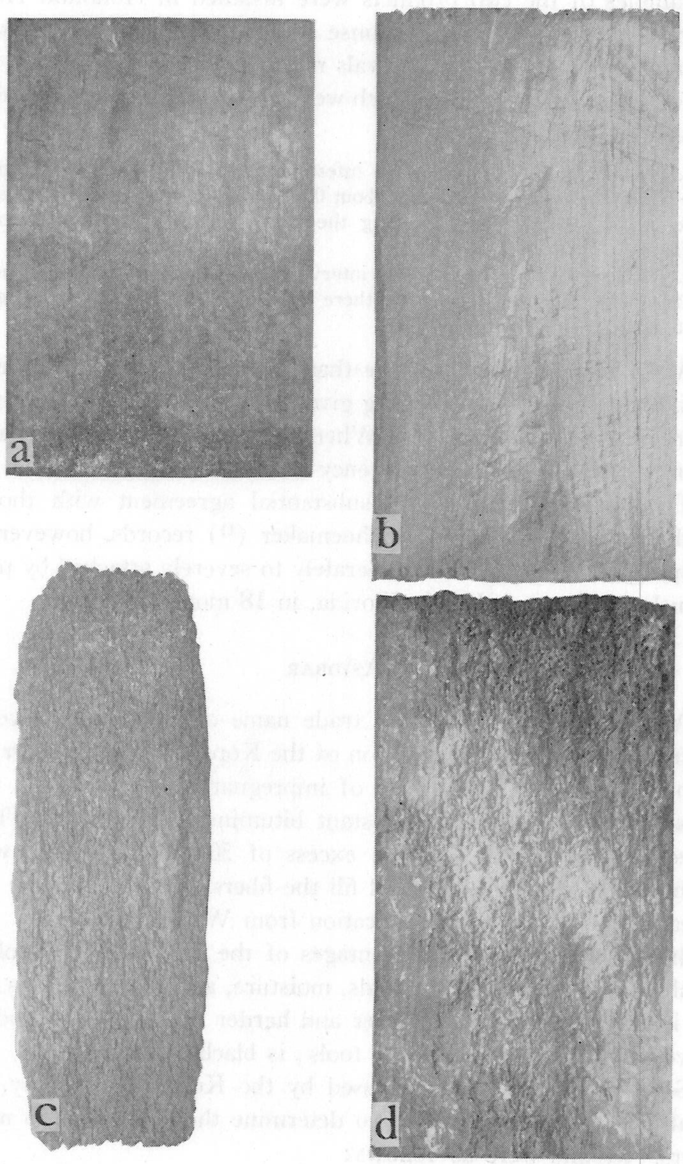


FIGURE 6.—**a,** Compreg (entire block), submerged for five years and three months; **b,** Asidbar (sawed block), submerged for two years and 42 days; **c,** creosoted *Sassafras,* submerged for four years, shows 25 percent destruction by the gribble; **d,** Asidbar (outer surface of *b*) shows action by the gribble.

Samples of the two products were installed in Honolulu Harbor in order to observe their response to the action of marine borers. Examination was made at intervals ranging from six months to more than five years. The results, which were identical for the two products, are as follows:

a. Submerged for 185 days: No infestation by marine borers. The surfaces of the blocks show many punctures about 0.5 mm. in depth, or about the diameter of the larval teredo shell, indicating the failure of the organisms to become established.

b. Blocks submerged for various intervals up to five years and three months: Results as for *a*. At no time was there infestation by teredos or the gribble (fig. 6, *a*).

After submergence for more than five years under severe conditions, both Impreg and Compreg give promise of immunity to marine borers for an indefinite period. When sawed in two, the blocks present a homogeneous resinous consistency of extreme hardness.

The above results are in substantial agreement with those of MacLean (7) for Compreg. Shoemaker (9) records, however, that Compreg and Impreg were moderately to severely attacked by pholad mollusks at Daytona Beach, Florida, in 18 months.

Asidbar

A wood product under the trade name of Asidbar is developed by the Wood Preserving Division of the Koppers Company, Orrville, Ohio. The processing consists of impregnation of the wood, under pressure, by a special acid-resistant bituminous compound. The injected materials are usually in excess of 50 percent of the weight of the wood, and they coat and fill the fibers to a considerable depth beneath the surface (communication from W. P. Arnold, 1). Some of the characteristics and advantages of the product are as follows: It inhibits the absorption of acids, moisture, and fumes; resists decay and insects; is somewhat heavier and harder than natural wood; can be worked with ordinary wood tools; is black in color.

Sections of Asidbar, processed by the Koppers Company, were installed in Honolulu Harbor to determine their response to marine borers. Results were as follows:

a. Submerged for 259 days: No attack by teredos; action by the gribble slight.

b. Submerged one year: No attack by teredos; increased, but slight, action by the gribble.

c. Submerged for two years and 42 days: No attack by teredos; moderate action by the gribble (fig. 6, *b, d*).

Asidbar responds to marine borers in much the same manner as does well-creosoted wood, and resistance to teredos and susceptibility to the gribble are quite similar in the two products. In Asidbar, however, there appears to be deeper penetration of the injected materials than is usually found in creosoted timbers.

Creosoted Wood

Creosote, an oily liquid distilled from wood or coal tar, is composed of phenols (carbolic acid) and their esters.

The impregnation of wood by this substance for preservation purposes has long been in practice, and the wide use of creosoted timbers in marine construction where concrete is not considered economical indicates that this process is still the leading one where long durability is desired. For piling and other supporting timbers in marine wharves and piers the creosoting treatment probably gives the best wood protection, in relation to cost, of any yet devised. That the use of wood thus treated is not practical for all purposes is, however, obvious. Other means must be sought for the protection of hulls of small boats and marine construction where wood is essential, but the creosoted product may not be suitable. Shoemaker (9) does not recommend creosoted planking for ships providing living quarters for persons below deck, because of the offensive odor. He states, however, that it may be suitable for barges and that, in spite of the odor of the preservative, it is sometimes used in vessels with living quarters below deck.

The significance of the few tests of creosoted wood in Honolulu Harbor during these investigations is that they were controlled as to time, making possible some definite evaluation of the progressive destruction caused by the gribble.

Test blocks of creosoted Douglas fir (commercial source) were installed in Honolulu Harbor at a depth of six feet, low tide. The creosote content of the wood was undetermined, but a high degree of saturation was indicated by the "bleeding" of the wood when nails were driven into it. Results after intervals of 133, 163, 209, 322, and 458 days were essentially similar except in degree. No infestation by teredos was noted at any time. Action by the gribble, however, was seen at each interval, the destruction increasing with length of submergence. In seven months the surfaces of test blocks were about 50 percent honeycombed to a depth of 5 mm.; in 10 months the entire surface of blocks was honeycombed; and in 15 months the destruction had reached a maximum depth of 10 mm.

Test blocks of *Sassafras* wood impregnated with creosote (distillation range 220-280) to the amount of 26 pounds per cubic foot were received from the Maritime Services Board of New South Wales, Australia, and installed in Honolulu Harbor with the following results:

a. Blocks submerged for one year and nine months: No attack by teredos; moderate destruction by the gribble.

b. Blocks submerged for two years: No attack by teredos; increasing destruction by the gribble.

c. Blocks submerged for four years: No attack by teredos. Approximately 25 percent of the test block destroyed by the gribble (fig. 6, *c*).

The results of these tests are in general agreement with those reported from other localities. It is common experience that, with respect to creosoted timbers, it is more difficult to control the action of the gribble than that of shipworms. The isopod frequently attacks creosoted wood which completely repels teredos. In Pearl Harbor creosoted Douglas fir piles 12-14 inches in diameter were completely severed by the gribble just below the water line during periods of five or six years. To render protection by creosote more effective some principle should be added which will check the ravages of the destructive isopod. This, however, may require long trial and error experimentation. Investigations of the Institution of Civil Engineers (Bryan, 3) in which highly toxic chemicals were added to creosote, even in amounts as high as five percent, indicated no practical benefit over plain creosote. It was concluded that the degree of efficiency of creosote in repelling marine borers was in direct ratio with the amount of absorption of the coal-tar product by the wood and the depth of its penetration.

It has been the general experience of investigators that surface application of creosote has not been very effective, owing to the rapid erosion of the material by action of sea water. I have had similar results with commercial roofing asphaltum applied to the surface of test blocks. The material is washed away in a few months leaving the wood vulnerable to attack by marine borers.

Plastics

SARAN RESIN X-124

This product which was developed and supplied by the Dow Chemical Company, Midland, Michigan, was dissolved to 20 percent solids in methyl ethyl ketone. Test blocks of white pine and California redwood were coated with this fluid plastic, applied by brush, and installed in Honolulu Harbor, along with controls, with the following results:

a. White pine blocks submerged for 236 days: No attack by teredos; action by the gribble slight. Controls riddled.

b. White pine blocks submerged for one year: Some blocks without attack, others infested by one or two small teredos, but no gribble. Controls riddled.

c. California redwood blocks submerged for one year: No attack by teredos or the gribble (fig. 7, *a*). Controls riddled (fig. 7, *b*).

d. California redwood blocks submerged 15 months: No attack by teredos or the gribble (fig. 7, *c*). Controls riddled (fig. 7, *d*).

SYNTHANE PLASTIC

A product under the trade name Synthane, developed by the Synthane Corporation, Oaks, Pennsylvania, was supplied by the producing company, at the request of the United States Navy, for the purpose of testing its resistance to marine borers. Samples of Synthane Grade C sheet material were installed in Honolulu Harbor and showed no attack by teredos or the gribble after submergence for 10 months. Unfortunately, the installation was lost soon after the first examination.

LIGNIN PLASTIC

Samples of a product believed to be a lignin plastic were supplied by George N. Wolcott. These were submerged in Honolulu Harbor for 70 days during which they were lightly attacked by numerous teredos with a maximum penetration of about 4 mm. No action by the gribble was noted.

Bakelite

A plate of Bakelite 14 mm. thick was submerged in Honolulu Harbor for 18 months. The glazed surfaces of the plate showed no evidence of attack by marine borers; but cut edges of the plate were

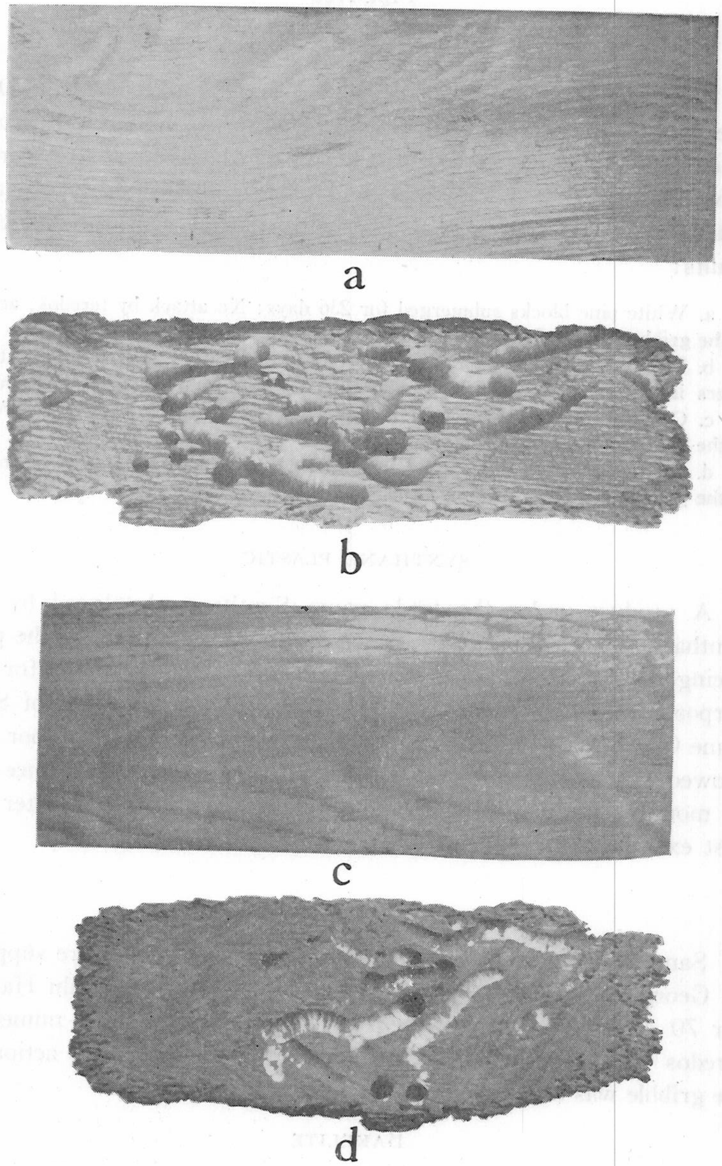


FIGURE 7.—Redwood: **a**, coated with Saran resin, submerged for one year; **b**, control of *a;* **c**, coated with Saran resin, submerged for 15 months; **d**, control of *c*.

attacked by teredo larvae, as indicated by numerous pits about 0.5 mm. deep, or the diameter of a larval shell. Larval shells remained in some of the pits. No teredos became established and there was no action by the gribble.

The attack of larval teredos on the cut edges of Bakelite and their attack on the surface of a highly resistant natural timber are strikingly similar. In both instances the shallow pits are evidence of failure of the larvae to penetrate deeply.

Masonite

Two grades of Masonite were examined for their reaction to marine borers. One was a thin product, 4 mm. thick; the other, known as Tempered Presdwood, was five-sixteenths inch thick. The results were as follows:

a. Thin form: Submerged in Kaneohe Bay and examined at intervals ranging from 45 to 376 days. Attacks by teredos observed at all intervals, but penetration slow. Maximum penetration in four months, 5 mm.; in 376 days, 55 mm. Action by the gribble slight, even during the longer intervals.

b. Tempered Presdwood: Submerged in Honolulu Harbor for 137 days. Badly damaged by teredos, maximum penetration 40 mm. Action by the gribble, moderate.

Marine Plywood

A five-ply product known as Marine Plywood was tested in Honolulu Harbor for its resistance to marine borers. After submergence for five months it was badly damaged by teredos and the gribble. The thin peripheral layers were almost entirely destroyed by the gribble, whereas teredos penetrated the three inner and thicker layers, freely cutting through the binding material from one layer to another.

Metal Bands

Test blocks of Douglas fir banded by strips of sheet copper and zinc one-half inch in width were tested for their comparative resistance to marine borers. The metal bands were attached one-half inch apart on some blocks and 20 mm. apart on others. Results were noted with respect to the difference in metals and in the spacing of the bands. Observations were made at a number of stations about Oahu as follows:

KANEOHE BAY

a. Test blocks transversely banded by six copper strips set one-half inch apart and others banded by zinc strips in a similar manner were submerged 148 days. Copper-banded blocks without infestation by marine borers; zinc-banded blocks moderately attacked by teredos and lightly by the gribble. Controls badly damaged by marine borers.

b. Blocks banded as in the preceding test were submerged 163 days. Copper-banded block attacked by a single teredo, penetration 15 mm.; action by the gribble negligible. Zinc-banded block heavily attacked by teredos, maximum penetration 80 mm.; damage by the gribble heavy. Controls riddled.

PEARL HARBOR

a. Test blocks transversely banded by six copper strips set one-half inch apart, and others banded by zinc strips in a similar manner were submerged 85 days. Copper-banded block moderately attacked by teredos; action by the gribble light (fig. 8, *a*). Zinc-banded block riddled by teredos and the gribble. Controls riddled (fig. 8, *b*).

b. Test block longitudinally banded by four copper strips set one-half inch apart was submerged 117 days. Block infested by two specimens of teredo, one penetrating 98 mm., the other 112 mm. Action by the gribble light.

WAIKIKI

A test block transversely banded by six copper strips set one-half inch apart was submerged for 73 days. It was not attacked by marine borers.

HANAUMA BAY

Test blocks longitudinally banded by two copper strips set 20 mm. apart and blocks banded in a similar manner by zinc strips were submerged for 70 days. The copper-banded blocks were attacked by two specimens of teredo, one penetrating 3 mm., the other 20 mm. (fig. 8, *c, e*). Action by the gribble was negligible. The zinc-banded blocks were moderately damaged by teredos and the gribble (fig. 8, *d, f*).

Since copper is known to possess greater antifouling properties than zinc, the general results of the above tests were to be expected. Without question, copper had the greater retarding influence on the activities of marine borers under the technique employed in the experiments. Although the attacks by larval borers were not completely inhibited, they were considerably hindered, even when copper bands were spaced at 20 mm. Zinc seems to have had little influence in checking the borers, even when the bands were placed within one-half inch of each other. In general, attacks by the gribble paralleled those of teredos, being heavy in zinc-banded blocks and light in those protected by copper.

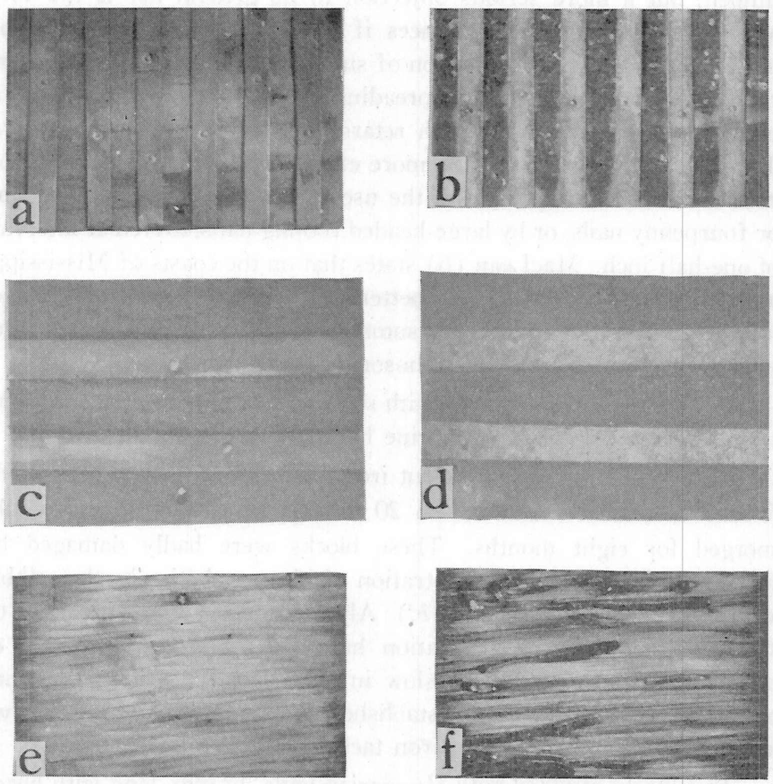


FIGURE 8.—Blocks banded by metal: a, outer surface of block with six transverse copper bands 0.5 inch apart, submerged for 85 days; b, outer surface of block with six transverse zinc bands 0.5 inch apart, submerged for 85 days; c, outer surface of block with longitudinal bands of copper 20 mm. apart, submerged for 70 days; d, outer surface of block with longitudinal bands of zinc 20 mm. apart, submerged for 70 days; e, block *c* sawed through middle shows two small teredos, maximum penetration 20 mm.; f, block *d* sawed through middle shows moderate damage by teredos and the gribble.

SCUPPER NAILING

Among the many suggested methods of protection against marine borers is scupper nailing, or studding the wooden surface with nails driven close together. It is now seldom employed; but if proper nails are used, the method seems to have considerable merit. Failure of this method has often been ascribed to the splitting or checking of the timber; but a more serious objection to its general use is the very slow process of treating surfaces if the nails are to be driven by hand. Furthermore, the selection of suitable nails, those which oxidize rapidly, is important, as the spreading of iron oxide in the wood is believed to be the factor which retards the action of marine borers. Thus iron nails are considered more effective than copper ones. Good results have been reported on the use of galvanized iron threepenny or fourpenny nails, or by large-headed roofing nails, driven at intervals of one-half inch. MacLean (6) states that on the coasts of Mississippi and Florida pine timbers are better protected if studded with steel nails than with copper ones. A summary of results of scupper nailing is recorded by Atwood and Johnson (2).

In Hawaii numerous tests with studded blocks of Douglas fir were made against the action of marine borers at Waikiki.

Test blocks, studded with cut iron tacks 15 mm. long, with heads 6 mm. in diameter and driven 20 mm. apart each way, were submerged for eight months. These blocks were badly damaged by teredos, with a maximum penetration of 90 mm. Action by the gribble was severe. (See figure 9, *a, b*.) Although, from the appearance of the wood, considerable oxidation had taken place at the time of observation, it probably was slow in starting, or did not start until after the teredos were well-established in the wood. Some burrows were within 0.25 mm. of an iron tack.

Test blocks studded with Hungarian nails, 12 mm. long with heads 8 mm. in diameter and driven one-half inch apart, were submerged three months. The blocks were heavily attacked by teredos and the gribble. Destruction of the studded blocks was about one-half that of untreated controls.

Test blocks studded with brass escutcheon nails, 18 mm. long with heads 4 mm. in diameter and driven one-half inch apart, were submerged for 98 days. They were badly damaged by teredos and the gribble (fig. 9, *c*). Destruction of the test block amounted to about 75 percent, or but little less than that of the untreated control.

Test blocks studded with twopenny galvanized iron nails driven 18 mm. apart were submerged for 13 months. They were heavily attacked by teredos, though quite superficially, with destruction of the block about 12 percent. The control was lost; but normally, untreated blocks are riddled at this station in three to four months.

Test blocks studded with threepenny galvanized iron nails driven one-half inch apart were submerged for four months. The blocks were lightly attacked by teredos, the maximum penetration 4 mm.; and

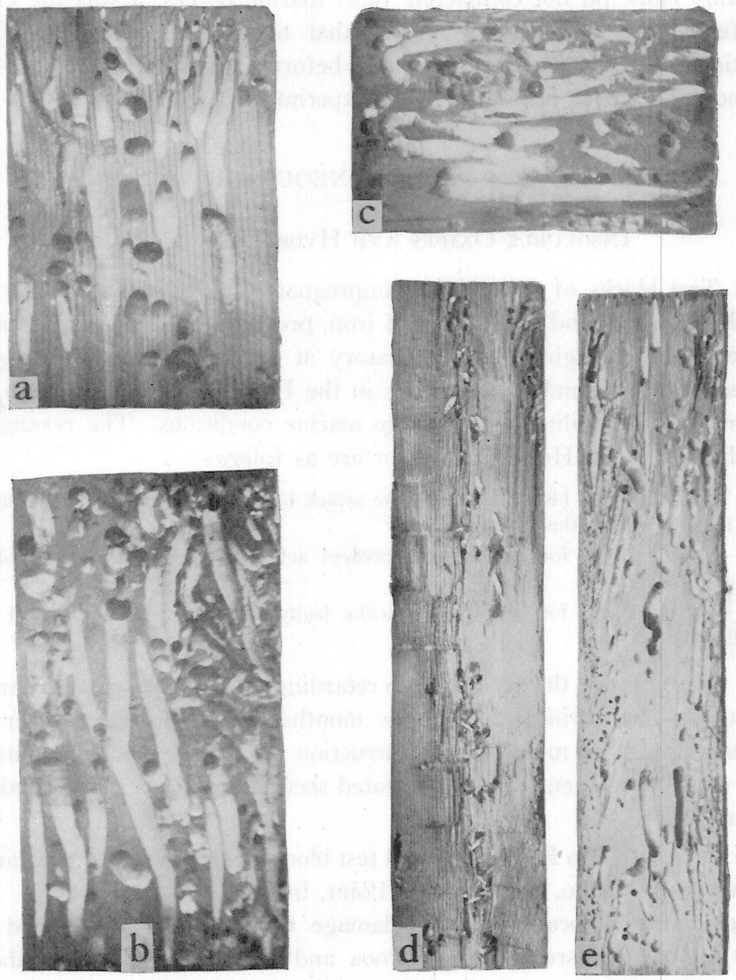


FIGURE 9.—Scupper nailing: **a,** cut iron tacks 20 mm. apart, submerged for eight months; **b,** control of *a;* **c,** brass escutcheon nails 0.5 inch apart, submerged for 98 days; **d,** galvanized threepenny nails 0.5 inch apart, submerged for four months (central portion marred by nail points, not by marine borers); **e,** control of *d.*

action by the gribble was slight (fig. 9, *d*). Destruction of the controls amounted to about 20 times that of the studded blocks (fig. 9, *e*).

From the above tests it is clear that the greater advantage rests with the small galvanized iron nails, especially when they are driven fairly close together. Although a one-half inch spacing of the threepenny nails did not completely repel marine borers, it was the most effective. It has been suggested that to increase the rapidity of oxidation, nails be dipped in acid before they are driven into the wood. This was not done in my experiments.

WOOD WITH MISCELLANEOUS TREATMENTS

Insoluble Oxides and Hydroxides of Iron

Test blocks of yellow pine, impregnated under pressure with insoluble oxides and hydroxides of iron, processed at the United States Naval Civil Engineering Laboratory at Solomons, Maryland, were installed at a number of stations in the Pacific, including Hawaii, to test their durability under severe marine conditions. The results of submergence in Honolulu Harbor are as follows:

a. Submerged 140 days: Moderate attack by teredos, maximum penetration 75 mm.; action by the gribble slight.

b. Submerged for 172 days: Increased action of teredos and the gribble (fig. 10, *a*).

c. Submerged for 285 days: Blocks badly damaged by teredos and the gribble.

The effect of this treatment in retarding the action of marine borers was obvious during the first few months of submergence. After an interval of nine months, the destruction of treated blocks amounted to about 50 percent that of untreated sections during a corresponding period.

In addition to Hawaii, treated test blocks were examined at Samoa, Kwajalein, Palau, and Sangley Point, in the Philippine Islands. At each of these localities heavy damage resulted during a period of 10 months. Destruction at Samoa and Kwajalein was due, about equally, to teredos and the gribble, whereas the gribble caused most of the damage at Palau. At Sangley Point the pholad mollusk, *Martesia aperta,* was a much more serious menace than either teredos or the gribble (fig. 10, *b*).

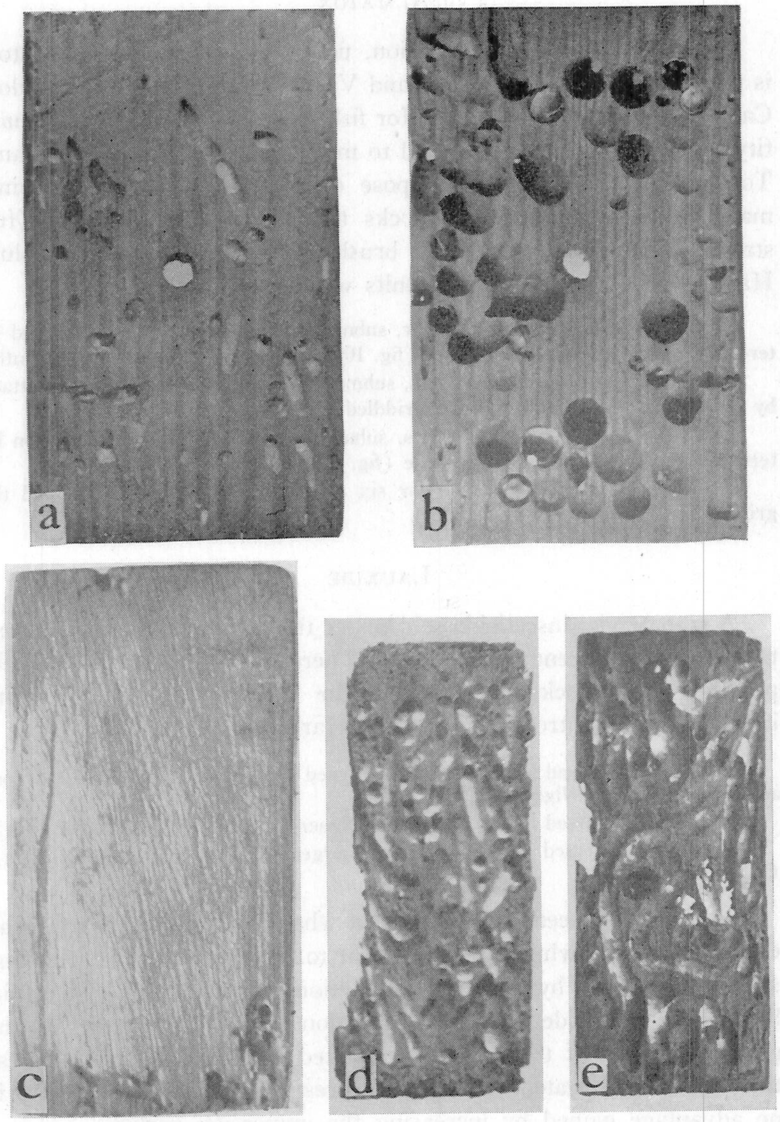


FIGURE 10.—**a,** iron oxide treatment, submerged in Honolulu Harbor for 172 days; **b,** iron oxide treatment, submerged at Sangley Point, Philippines, for five months; **c,** Almatox, immersed for 30 hours and submerged for 10 months; **d,** Almatox, painted, submerged for six months; **e,** Almatox, immersed for one hour, submerged for eight months.

Almatox

A copper naphthenate solution, under the trade name Almatox, is produced by the Alma Paint and Varnish Company, Ltd., London, Canada, as a protective coating for fishing nets and cordage. A quantity of the solution was supplied to me by M. Gurvey and Company, Toronto, Canada, for the purpose of testing the product against marine wood borers. Test blocks treated with the solution (full strength) by immersion and by brushing were installed in Honolulu Harbor, with controls. The results were as follows:

a. Blocks immersed for one hour, submerged for eight months: Riddled by teredos; action by the gribble slight (fig. 10, *e*). Controls riddled in four months.

b. Blocks immersed for 24 hours, submerged for eight months: Light attack by teredos and the gribble. Controls riddled.

c. Blocks immersed for 30 hours, submerged for 10 months: No action by teredos; slight damage by the gribble (fig. 10, *c*). Controls riddled.

d. Blocks painted, submerged for six months. Riddled by teredos and the gribble (fig. 10, *d*). Controls riddled.

Lauxide

A commercial insecticide sold under the trade name Lauxide contains DDT, 5 percent; pyrethrin, 0.05 percent; and volatile oils, 94.95 percent. Test blocks immersed in the full-strength solution were installed, with controls, in Honolulu Harbor.

a. Blocks immersed for 24 hours, submerged for 98 days: Riddled by teredos; action by the gribble light. Controls riddled.

b. Blocks immersed for 48 hours and submerged for 98 days: Results as in *a*.

c. Blocks immersed for 24 hours, submerged for 274 days: Results as in *a* (fig. 11, *a*, *b*).

These results seem to indicate that whatever repelling factors may exist in Lauxide which are repugnant to teredos, they are soon dissipated, probably by the leaching action of sea water. There is, however, some evidence that the solution retards the activity of the gribble. Action of the isopod on treated blocks was markedly less than that on untreated controls. The results also show that there is no advantage gained by increasing the immersion period.

Termicide

Another well-known insecticide, called Termicide, is a 5 percent pentachlorophenol solution which showed some retarding effect upon

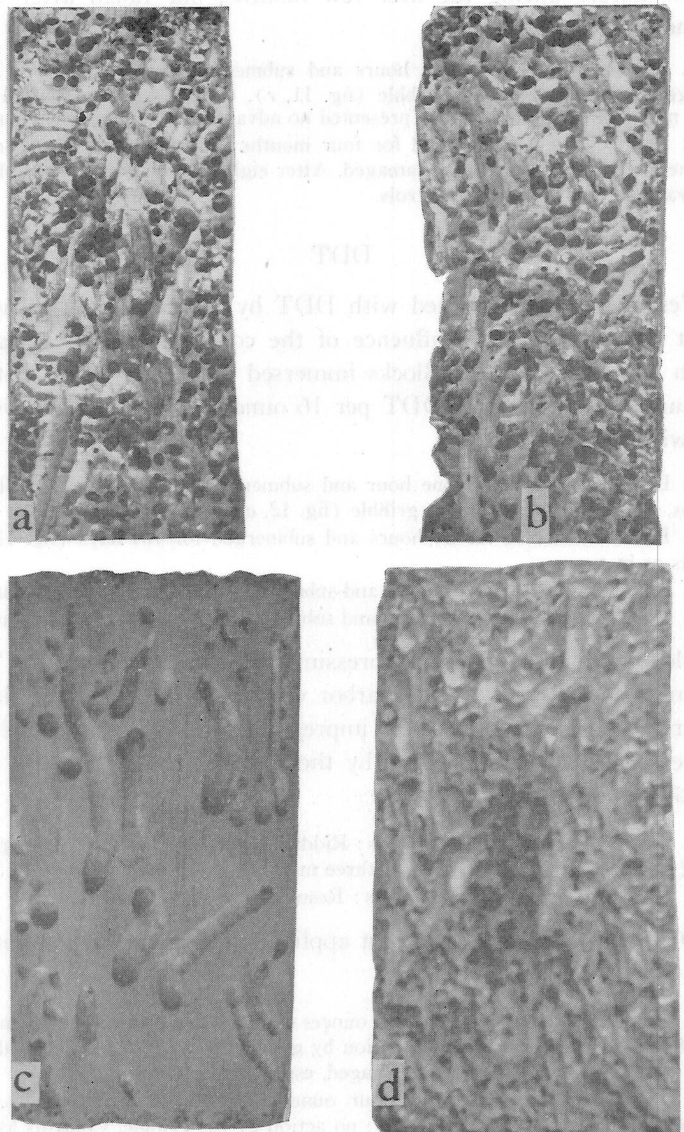


FIGURE 11.—a, Lauxide, immersed for 24 hours, submerged for 274 days; b, control of *a;* c, Termicide, immersed for 30 hours, submerged for six months; d, control of *c.*

marine borers during the first few months, but failed after about six months.

a. Blocks immersed for 30 hours and submerged for six months: Badly damaged by teredos and the gribble (fig. 11, *c*). Controls riddled (fig. 11, *d*). After nine months treated blocks presented no advantage over untreated controls.

b. Painted blocks submerged for four months: Lightly attacked by teredos and the gribble. Controls badly damaged. After eight months such blocks showed no advantage over untreated controls.

DDT

Test blocks were treated with DDT by three methods in an attempt to determine the influence of the compound in checking the action of marine borers. Blocks immersed in DDT solution without pressure (one-half ounce DDT per 16 ounces of kerosene) gave the following results.

a. Blocks immersed for one hour and submerged for 104 days: Riddled by teredos, with little action by the gribble (fig. 12, *a*). Controls riddled.

b. Blocks immersed for 24 hours and submerged for 104 days (fig. 12, *b*): Results as in *a*.

c. Blocks immersed for 45 hours and submerged for 188 days: Results as in *a*.

d. Blocks immersed for 48 hours and submerged for 409 days: Results as in *a*.

Blocks impregnated under pressure were processed by the Yard Testing Laboratory at Pearl Harbor with a 2 percent DDT solution in kerosene. On analysis of an impregnated block it was found that 1.5 percent DDT was retained by the wood. The experiments gave the following results.

a. Blocks submerged for 158 days: Riddled by teredos; action by the gribble light (fig. 12, *c*). Controls riddled in three months.

b. Blocks submerged for 207 days: Results as in *a* (fig. 12, *d*).

DDT was also added to paint applied to the test blocks by brush, with the following results.

a. DDT (one-half ounce per four ounces of common white paint), submerged for 158 days: Riddled by teredos; action by gribble light. Controls (treated with white paint lacking DDT) badly damaged, especially by teredos.

b. DDT (one-half ounce per four ounces of common white paint), submerged 239 days: Riddled by teredos; no action by the gribble. Controls as in *a*.

c. DDT (one ounce per four ounces of common white paint), submerged 219 days: Badly damaged by teredos; no action by the gribble. Controls as in *a*.

Test blocks treated by DDT solution, either by immersion without pressure or under pressure, appear to be repugnant to the gribble

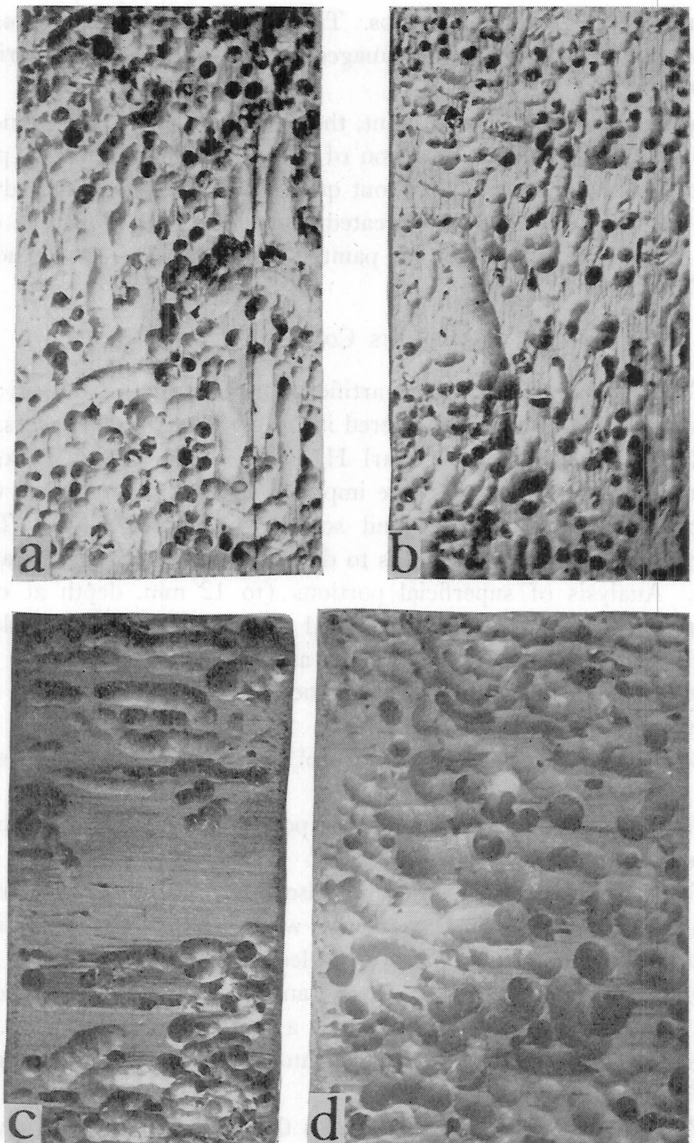


FIGURE 12.—DDT treatments: **a,** immersed for one hour, submerged for 104 days; **b,** immersed for 24 hours, submerged for 104 days; **c,** applied under pressure, submerged for 158 days; **d,** DDT in kerosene, applied under pressure, submerged for 207 days.

but not appreciably so to teredos. Test blocks immersed in kerosene for only 45 hours were badly damaged by both teredos and the gribble in 105 days.

In the experiments with paint, there seemed to be some influence of DDT in slowing up the action of the gribble, but controls (paint without DDT) also brought about quite similar results. Any advantage resulting from the fully treated test blocks over unpainted controls was obviously due to the paint itself rather than to the added DDT.

Siliceous Compounds

To determine whether the artificial introduction of certain siliceous compounds into wood altered its response to marine borers, the Yard Testing Laboratory, Pearl Harbor, processed test blocks of sugar pine under pressure. The impregnating compounds used were silicic acid, sodium silicate, and sodium silicate with HCl. Tests were made of the treated blocks to determine the amount of retained silica. Analysis of superficial portions (to 12 mm. depth at ends, 4 mm. depth on lateral surfaces) and deeper portions of the blocks showed the amount of retained silica as follows:

Silicic acid: Outer portion of block, 2.18 percent; deeper, 1.69 percent.

Sodium silicate: Outer portion of block, 0.88 percent; deeper, 0.57 percent.

Sodium silicate with HCl: Outer portion of block, 0.78 percent; deeper, 0.26 percent.

The Yard Testing Laboratory also determined the amount of silica leaching from a highly silicated wood while submerged during a given period. Forty grams of drilled sample of *Antidesma pulvinatum*, which has a silica content ranging as high as 3.3 percent, were covered with distilled water for a period of three months. At the end of this period only 0.0068 gram of silica was present in the distilled water.

Processed blocks impregnated with the siliceous compounds were installed in Honolulu Harbor, with controls. The results were as follows:

a. Silicic acid: Blocks submerged for 145 days. Moderate damage by teredos and heavy attacks by the gribble resulted (fig. 13, *a*). There was no appreciable advantage over untreated controls.

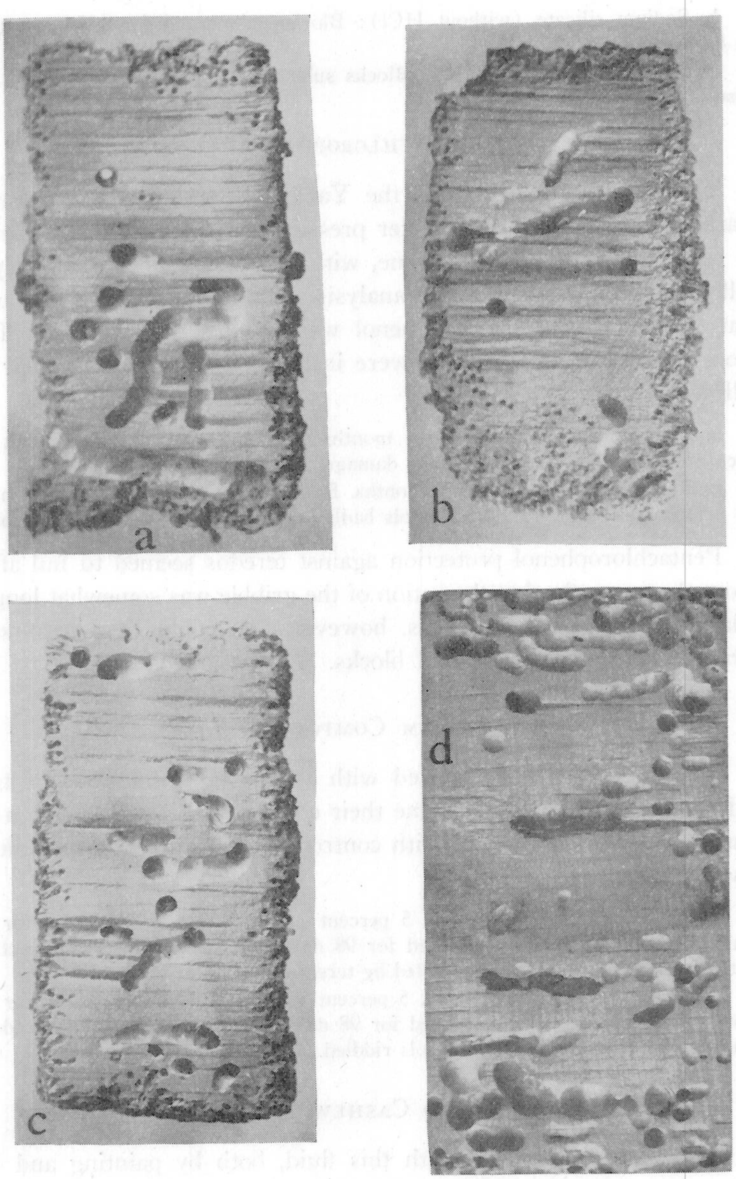


FIGURE 13.—Treatments applied under pressure: **a**, silicic acid, submerged for 145 days; **b**, sodium silicate (without HCl), submerged for 145 days; **c**, sodium silicate (with HCl), submerged for 145 days; **d**, pentachlorophenol (3 percent), submerged for five months.

b. Sodium silicate (without HCl): Blocks submerged for 145 days (fig. 13, *b*). Results as in *a*.

c. Sodium silicate with HCl: Blocks submerged for 145 days (fig. 13, *c*). Results as in *a*.

PENTACHLOROPHENOL

Test blocks, processed by the Yard Testing Laboratory, Pearl Harbor, were impregnated under pressure with a 3 percent solution of pentachlorophenol in kerosene, with 100 cc. of alcohol added per gallon to hasten solubility. On analysis of treated blocks it was found that 1.4 percent pentachlorophenol was retained in the wood. The processed blocks and controls were installed in Honolulu Harbor as follows:

a. Blocks submerged for three months. Action by teredos very light; a trace of the gribble. Controls badly damaged.

b. Blocks submerged for five months. Badly damaged by teredos; action by the gribble light (fig. 13, *d*). Controls badly damaged, especially by the gribble.

Pentachlorophenol protection against teredos seemed to fail after about three months, but the action of the gribble was somewhat longer delayed. In about six months, however, the gribble had become a serious menace to the treated blocks.

SODIUM COMPOUNDS

Wood samples were treated with the aqueous solutions of two sodium compounds to determine their effect, if any, on the action of marine borers. Test blocks with controls were installed in Honolulu Harbor as follows:

a. Sodium pentachlorophenate, 5 percent solution: Blocks immersed for 48 hours, without pressure; submerged for 98 days. No attack by teredos; action by the gribble slight. Controls riddled by teredos and the gribble.

b. Sodium orthophenylphenate, 5 percent solution: Blocks immersed for 48 hours, without pressure; submerged for 98 days. Moderate damage by teredos; attack by the gribble severe. Controls riddled.

CHLORINATED CASHEW NUT FLUID

Wood samples treated with this fluid, both by painting and by immersion, were installed in Honolulu Harbor, with controls, as follows:

a. Painted blocks submerged for 177 days: Light attacks by teredos and the gribble. Controls riddled.

b. Painted blocks, submerged for 224 days: Moderate damage by teredos; action by the gribble light. Controls riddled.

c. Painted blocks, submerged for 261 days: Moderate damage by teredos and the gribble. Controls riddled.

d. Blocks immersed for 16 hours and submerged for 191 days: Lightly attacked by teredos and the gribble. Controls riddled.

Antifouling Paints

Commercial antifouling paints of good quality have considerable merit in inhibiting the attachment to surfaces of fouling organisms such as barnacles, bryozoans, and serpulid worms. Since these organisms become affixed while in the larval state, it may be assumed that the toxicity of the coatings will also repel the larvae of shipworms (bivalve mollusks), or be fatal to crustacean forms like the gribble when they attempt to penetrate the treated surface.

To compare the potency of a few of the commercial products against the action of marine borers, controlled observations were made with test blocks coated with paints under the trade names of Yacht Green, Copper Red, and Cape Cod. Two coats of the paint were applied by brush and the test blocks installed where they would be free from abrasion. Controls were used for comparison. A number of different woods, as well as the different paints, were used in the experiments, the results of which follow:

DOUGLAS FIR

a. Coating of Copper Red; blocks submerged for three months: No attack by marine borers (fig. 14, *a*). Controls badly damaged by teredos and the gribble (fig. 14, *b*).

b. Coating of Yacht Green; blocks submerged for seven months: No attack by marine borers. Controls badly damaged by teredos and the gribble.

c. Coating of Cape Cod; blocks submerged for one year: No attack by marine borers. Controls riddled in four months.

d. Coating of Cape Cod; blocks submerged for 17 months: No attack by marine borers (fig. 14, *c*). Controls riddled.

SUGAR PINE

a. Coating of Copper Red; blocks submerged for five months: No attack by marine borers. Controls riddled in four months.

b. Coating of Copper Red; blocks submerged for nine months: No attack by marine borers. Controls riddled.

c. Coating of Copper Red; submerged for one year: No attack by marine borers. Controls riddled.

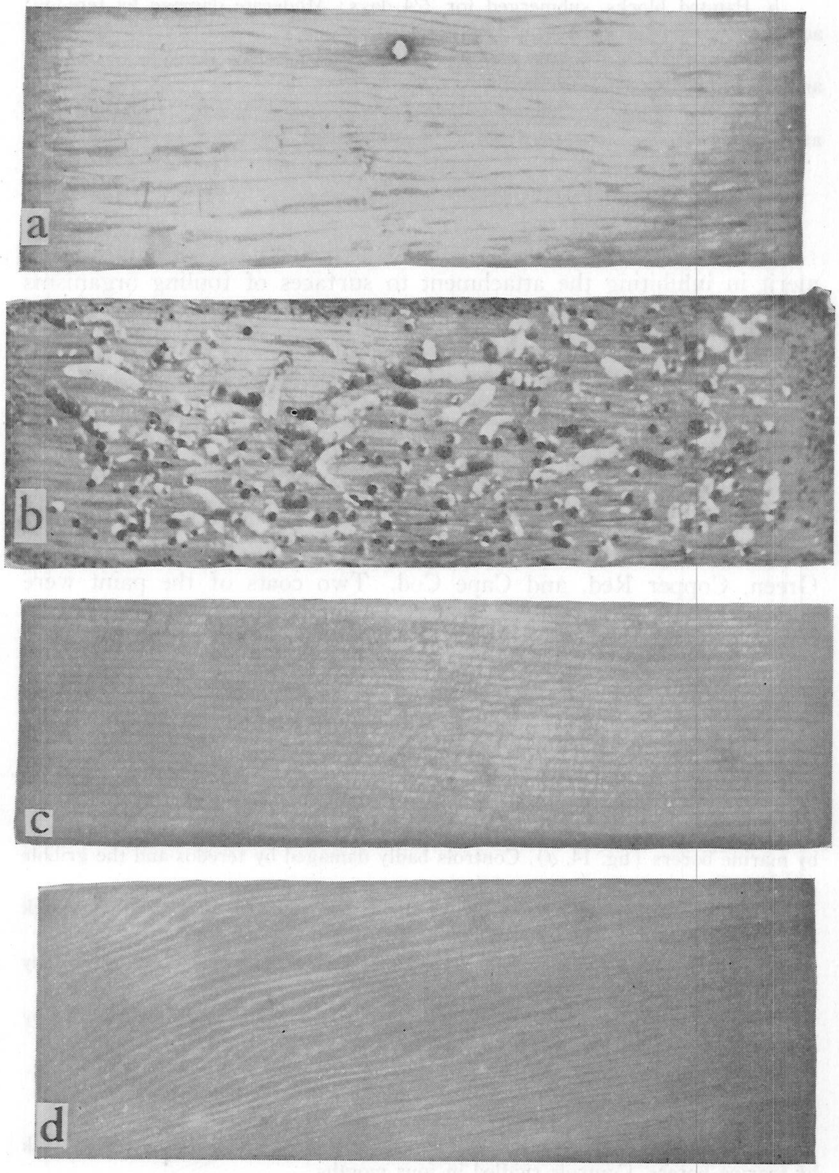


FIGURE 14.—Antifouling paints: **a,** Douglas fir painted with Copper Red, submerged for three months; **b,** control of *a;* **c,** Douglas fir painted with Cape Cod, submerged for 17 months; **d,** redwood painted with Cape Cod, submerged for two years.

CALIFORNIA REDWOOD

a. Coating of Cape Cod; submerged for 19 months: No attack by marine borers. Controls riddled in six months.

b. Coating of Cape Cod; submerged for two years: No attack by marine borers (fig. 14, *d*). Controls riddled.

SOUTHERN CYPRESS

Coating of Cape Cod; submerged for eight months: Lightly attacked by teredos and the gribble. Considerable erosion of the paint was noted. Controls riddled in six months.

WEST INDIAN MAHOGANY

Coating of Copper Red; submerged for eight months. Moderate damage by teredos and the gribble. Much erosion of the paint had taken place. Controls riddled in six months.

It is concluded from the short-interval tests recorded that a good antifouling paint properly applied may protect susceptible wood in sea water for periods upward of two years. However, the chance of such treated wood becoming scarred, or of the paint becoming eroded from other causes, is very great. For long-time service in sea water the coating of timbers in this manner would give little assurance of protection; but for short intervals, or for temporary maritime construction where service for periods of two or three years is desired, such treatment may be worthy of consideration.

A practical protection of small boats with wooden hulls is to select planking which possesses some inherent qualities of resistance and to keep the surface in contact with sea water well coated with a good antifouling paint.

Nuodex Products

The Nuodex Products Company produces a number of chemical compounds which tests show to be successful against decay and wood destroying insects. Some of these have been tested in Hawaii against marine borers by means of treated test blocks. Goll (4) has listed the chief constituents of five of the products utilized in my investigations as follows: Nuocide D-23, a copper salt of cyclopentane propionic acids carrying 6 percent copper expressed as metal; Nuocide Copper 8, a standardized copper naphthenate carrying 8 percent copper expressed as metal; Nuocide 321 (comparable to Nuocide D-26), a mercury salt of cyclopentane propionic acids carrying 10 percent mercury as metal; Nuocide Cadmium 8, a standardized cadmium naphthenate carrying 8 percent metal; and Nuocide Zinc 8, a standardized zinc naphthenate carrying 8 percent zinc as metal.

Test blocks, either immersed in or painted by the solutions (full strength), produced the following data and results:

IMMERSED TEST BLOCKS

a. Immersed in D-23 for one minute; submerged for seven months: No attack by teredos or the gribble (fig. 15, *a*). Controls badly damaged.

b. Immersed in D-23 for one minute; submerged for one year: Light attack by teredos and the gribble (fig. 15, *b*). Controls riddled.

c. Immersed in D-23 for one hour; submerged for one year: No attack by teredos; a trace of the gribble. Controls riddled.

d. Immersed in Copper 8 for one hour; submerged for 153 days: No attack by teredos or the gribble. Controls badly damaged.

e. Immersed in Copper 8 for one hour; submerged for one year: Riddled by teredos and the gribble. Controls riddled.

f. Immersed in Nuocide 321 for one hour; submerged for 153 days: No attack by teredos or the gribble (fig. 15, *c*). Controls badly damaged (fig. 15, *d*).

g. Immersed in Zinc 8 for one hour; submerged for nine months: Badly damaged by teredos and the gribble. Controls riddled.

h. Immersed in Cadmium 8 for one hour; submerged for nine months: Blocks almost totally destroyed; no advantage over controls.

PAINTED TEST BLOCKS

a. Painted with D-23; submerged for 18 months: No attack by teredos or the gribble. Controls riddled in four months.

b. Painted with Copper 8; submerged for 153 days: No attack by teredos or the gribble. Controls badly damaged.

c. Painted with Copper 8; submerged for one year: Badly damaged by teredos; moderate damage by the gribble. Controls riddled.

For additional results with Nuocide products consult table 2.

SPECIAL CHEMICAL TREATMENTS

As I mentioned in the introduction to this paper, George N. Wolcott of the Agricultural Experiment Station of the University of Puerto Rico supplied me with a large number of test blocks treated according to his standard technique (dipped 10 minutes, or longer in a few instances), for the purpose of evaluating the merit of various chemical compounds in repelling marine borers in Hawaiian waters.

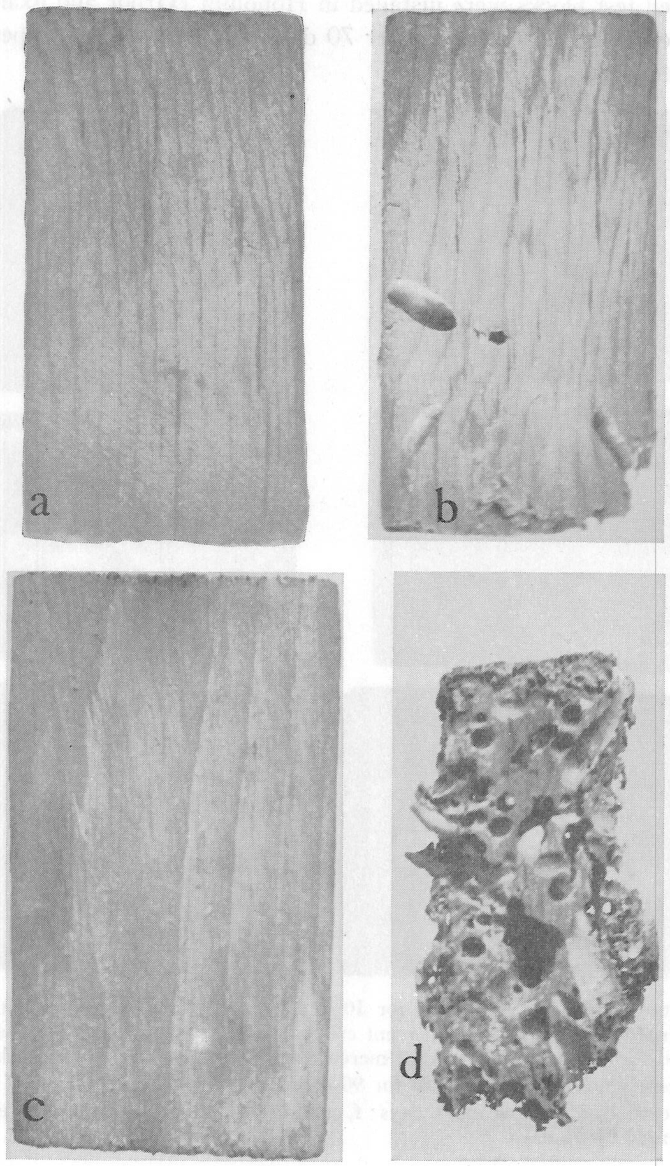


FIGURE 15.—Nuocide treatment (solutions full strength): **a**, D-23, dipped for one minute, submerged for seven months; **b**, D-23, dipped for one minute, submerged for one year; **c**, Nuocide 321, immersed for one hour, submerged for 153 days; **d**, control of *c*.

Treated test blocks were installed in Honolulu Harbor and examined at intervals, most of them after 70 days, a few after longer periods. (See figure 16.)

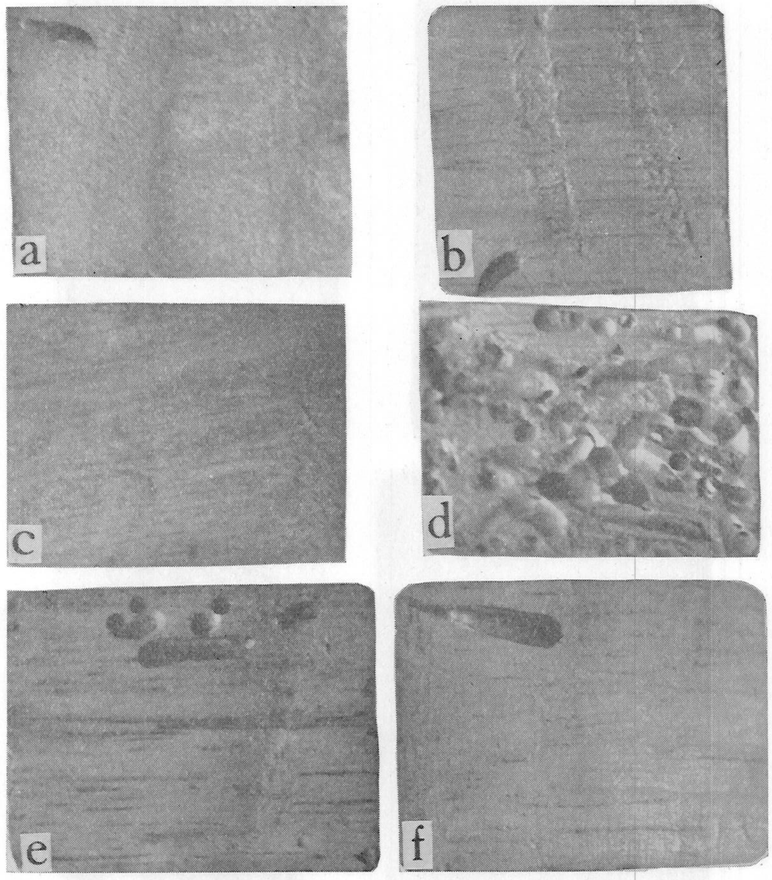


FIGURE 16.—Blocks dipped for 10 minutes: **a**, 8 percent zinc naphthenate, submerged for 70 days; **b**, 2 percent crude chlorinated 60 percent terpenes, submerged for 70 days; **c**, 2 percent mercurous nitrate, submerged for 70 days; **d**, 2 percent pinosylvin, submerged for 90 days; **e**, 50 percent chlorinated (18 percent) cardol, submerged for 70 days; **f**, crystalline chlorinated 60 percent terpenes, submerged for 70 days.

In table 2 are set forth the chemical compounds with which the wood was treated, the duration of submergence, and the results. Figure 16 illustrates the results of some of the tests.

Table 2.—Chemicals for Treatment of Wood

CHEMICALS	PERCENT	TREATMENT (DIPPED)	TESTING TIME	RESULTS	
				TEREDOS	GRIBBLE
Alizarin, copper lake	1	24 hrs.	220 days	badly damaged	no attack
Alizarin, purple	2	24 hrs.	70 days	heavy attack	light attack
Anacardic acid, chlorinated	10	10 min.	70 days	riddled	light attack
Anthragallol, copper lake	1	24 hrs.	199 days	badly damaged	no attack
Anthrarufin and Chrysazin, copper lake	1	24 hrs.	199 days	badly damaged	a trace
Benzene hexachloride, gamma isomer	2	10 min.	9 months	riddled	?
Cadmium naphthenate	4	10 min.	70 days	light attack	light attack
Cardol, crude chlorinated (18%)	10	10 min.	70 days	heavy attack	light attack
Cardol, crude chlorinated (18%)	20	10 min.	70 days	light attack	light attack
Cardol, crude chlorinated (18%)	50	10 min.	70 days	light attack	light attack
Copper dimethyl dithio carbamate	0.2	10 min.	70 days	heavy attack	light attack
Copper naphthenate	4	10 min.	70 days	heavy attack	light attack
Copper naphthenate	8	10 min.	70 days	moderate attack	light attack
Copper pentachlorophenate	0.5	10 min.	70 days	heavy attack	light attack
Copper pentachlorophenate	1	10 min.	70 days	heavy attack	light attack
Copper pentachlorophenate	2	10 min.	70 days	heavy attack	no attack
Copper selenite	0.2	10 min.	224 days	badly damaged	light attack
Copper selenite	0.4	10 min.	224 days	riddled	a trace
Crude chlorinated 60% terpenes	2	10 min.	70 days	light attack	no attack
Crude chlorinated 60% terpenes	5	10 min.	70 days	light attack	no attack

Table 2.—Chemicals for Treatment of Wood—Continued

Chemicals	Percent	Treatment (dipped)	Testing time	Results	
				Teredos	Gribble
Crystalline chlorinated 60% terpenes	2	10 min.	70 days	heavy attack	no attack
Crystalline chlorinated 60% terpenes	5	10 min.	70 days	light attack	light attack
Cupric fluoride	0.1	10 min.	70 days	moderate attack	no attack
Cupric fluoride	0.2	10 min.	70 days	moderate attack	light attack
1, 1-Diphenyl (4-hydroxy-3, 5-dichlor) 2, 2, 2-Trichlorethane	2	10 min.	70 days	riddled	?
Dihydropinosylvin monomethyl ether	1	10 min.	90 days	riddled	no attack
Dimethyl tetrachlorophthalate	2	10 min.	90 days	riddled	no attack
Ferric naphthenate	4	10 min.	70 days	moderate attack	light attack
Ferric naphthenate	8	10 min.	70 days	heavy attack	light attack
Lead naphthenate	2	10 min.	70 days	heavy attack	light attack
Mercurous nitrate	1	10 min.	70 days	light attack	light attack
Mercurous nitrate	2	10 min.	70 days	light attack	light attack
Mercurous sulfate	0.1	10 min.	70 days	heavy attack	light attack
Methoxylchlor	2	10 min.	90 days	riddled	no attack
Nuocide D-23	10	10 min.	70 days	medium attack	light attack
Nuocide D-23	100	10 min.	70 days	light attack	light attack
Nuocide D-26	10	10 min.	70 days	heavy attack	moderate attack
Nuocide D-26	100	10 min.	70 days	light attack	moderate attack
Phosphorus bromide	2	10 min.	70 days	heavy attack	heavy attack

Table 2.—Chemicals for Treatment of Wood—Continued

Chemicals	Percent	Treatment (dipped)	Testing time	Results	
				Teredos	Gribble
Phosphorus bromide	5	10 min.	70 days	heavy attack	heavy attack
Pinosylvin	2	10 min.	90 days	riddled	no attack
Pinosylvin dimethyl ether	1	10 min.	90 days	riddled	no attack
Pinosylvin monomethyl ether	1	10 min.	90 days	riddled	no attack
Pyridylmercuric chloride	1	10 min.	70 days	heavy attack	heavy attack
Pyridylmercuric stearate	1	10 min.	70 days	heavy attack	moderate attack
Polyvinyl acetate and 0.2% cu. as copper selenite	25	10 min.	224 days	riddled	moderate attack
Quinalizarin	1	10 min.	70 days	heavy attack	light attack
Stilbene	2	10 min.	90 days	riddled	no attack
Tectoquinone	2	10 min.	70 days	moderate attack	moderate attack
Thanite	5	10 min.	70 days	heavy attack	moderate attack
Thanite	10	10 min.	70 days	heavy attack	heavy attack
Thanite	100	10 min.	70 days	heavy attack	moderate attack
Xanthone	2	10 min.	70 days	heavy attack	moderate attack
X-naphthaflavone	2	10 min.	70 days	heavy attack	moderate attack
Zinc dimethyl dithio carbamate	2	10 min.	70 days	heavy attack	heavy attack
Zinc fluoride	0.2	10 min.	70 days	heavy attack	moderate attack
Zinc fluoride	0.1	10 min.	70 days	heavy attack	light attack
Zinc fluoride	0.05	10 min.	70 days	medium attack	light attack
Zinc naphthenate	4	10 min.	70 days	light attack	light attack
Zinc naphthenate	8	10 min.	70 days	light attack	no attack

DISCUSSION AND SUMMARY

The above report on the response of marine borers to various wood treatments will impress one at once with how few chemical compounds, under the artificial techniques employed, have any appreciable influence in checking the activities of either teredos or the gribble. However, if due consideration is given the potent erosive action and leaching property of sea water, the results are not surprising. Since many of the ingredients of the treating substances are water soluble, whether on superficial application or shallow injection into the wood, they are exposed to rapid dissipation when in contact with the sea.

The chief feature of the investigations is that they offer many indicators, mostly on the negative side, a few of which may prove to be significant. A number of general conclusions can be summarized from the series of experiments.

Certain processed woods such as Arboneeld (impregnated with methylolurea) and Chemonite (impregnated with copper and arsenic salts) presented marked resistance to marine borers. Although not developed for such service, both of these products would, no doubt, stand up well in sea water for short-time projects involving periods of two or three years.

Transmuted wood products, such as Impreg and Compreg, give promise of indefinite durability in sea water. Under severe conditions these products resisted all attacks by marine borers for more than five years, or the duration of the test. The only appreciable effect of the submergence was a dulling of the polished surface of the test samples.

Molluscan borers (teredos) and crustacean borers (gribble) respond quite differently to certain chemical compounds. Asidbar and creosoted wood inhibit the action of teredos for indefinite periods, whereas the gribble often seems to thrive on the treated products. This is shown, not only by experimental test blocks, but by the fact that creosoted piling frequently fails due to the destructive action of the gribble alone. In my experiments, DDT solutions applied with or without pressure appeared consistently to check the action of the gribble but seemed to have little effect on teredos.

Saran plastic X-124 and Synthane sheet material indicated considerable resistance to marine borers. The former product was without attack for one year, the latter without attack for 10 months, soon after which the installation was lost.

Copper bands are much more effective than zinc bands in repelling marine borers when applied to sections of wood. The advantage of copper over zinc is noted when the spacing of the bands is one-half inch or increased to 20 mm.

Scupper nailing accomplishes results if rapidly oxidizing nails are selected and they are driven close enough together. My tests gave the best results with threepenny galvanized nails driven one-half inch apart.

Insecticides, in general, whether applied superficially or injected into the wood, have little merit in checking the action of marine borers. Whatever initial toxicity they may have is usually quickly dissipated in sea water. A graduated duration of submergence gives some indication of the rapidity of the dissolution of the protective elements.

Antifouling paints of good quality offer effective temporary protection against marine borers. However, abrasion, checking of the surface, or erosion of the coating may counteract advantages of the paint. This method of protecting the wooden hulls of boats is usually the most practical and economical. Such paints may also protect temporary installations in contact with sea water where paints can be applied and are suitable. They should repel marine borers for two or three years, possibly longer.

The addition of siliceous compounds, under pressure, to susceptible test blocks had little influence in checking marine borers. In case of silicic acid, the retained amount of silica in the outer portion of experimental blocks was as much as 2.18 percent, in the deeper portion as much as 1.69 percent. Wolcott (16) expressed a similar opinion with respect to compounds of silica applied to wood in an attempt to make it more resistant to termites.

Some of the Nuodex products gave indications of considerable resistance to marine borers during intervals up to 18 months. Among those examined, Nuocide D-23, carrying 6 percent copper, proved one of the most effective. Test blocks immersed in D-23 (10 percent, 100 percent) or painted with it were utilized in the experiments. Wood impregnated by D-23, applied under pressure, should be even more capable of repelling marine borers.

From the list of chemical compounds in table 2, many of which have proved effective against termites, few can be selected showing any marked degree of protection against marine borers. Among the more satisfactory teredo repellents are zinc naphthenate, mercurous nitrate, the stronger compounds of crude cardol, and both crude and crystalline terpenes. With modified treatment technique and more adequate impregnation of the wood, other compounds might be added to these few. A considerable number of the chemicals seemed to be repugnant to the gribble, which indicates that molluscan and crustacean borers differ from each other in their likes and dislikes.

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