NRL Report 7417

Termite Resistance of Polyvinyl Chloride Plastics in Southern Temperate and Tropical Environments

Final Report of Phase 1 – Effect of Plasticizers and Insecticides

J. D. BULTMAN AND C. R. SOUTHWELL

Marine Biology and Biochemistry Branch
Ocean Sciences Division

and

RAYMOND H. BEAL

United States Department of Agriculture, Forest Service
Wood Products Insect Laboratory
Gulfport, Miss.

June 28, 1972

NAVAL RESEARCH LABORATORY
Washington, D.C.

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Research Laboratory Washington, D.C. 20390	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

TERMITE RESISTANCE OF POLYVINYL CHLORIDE PLASTICS IN SOUTHERN TEMPERATE AND TROPICAL ENVIRONMENTS, FINAL REPORT OF PHASE 1—EFFECT OF PLASTICIZERS AND INSECTICIDES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

This is a final report on this phase of the problem; work is continuing on other phases.

5. AUTHOR(S) (First name, middle initial, last name)

J.D. Bultman, C.R. Southwell, and R.H. Beal

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 28, 1972	22	11

8a. CONTRACT OR GRANT NO. NRL Problem G04-01 b. PROJECT NO. RR 104-03-41-5503 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NRL 7417 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Department of the Navy (Naval Facilities Engineering Command) Washington, D.C. 20360

13. ABSTRACT

One phase of the investigation on the termite resistance of various experimental polymeric materials has been completed. Thirty-two formulations containing polyvinyl chloride resin were prepared incorporating, variously, four plasticizers and three toxicants. Of the 320 specimens exposed for 75 months in the Panamanian jungle, 135 specimens (42%) showed evidence of attack, ranging from light to heavy, although in general the attack was light; 79 specimens (25%) of the 320 specimens exposed for 60 months in the pine woods of Mississippi also showed evidence of attack, generally light. The 42 damaged specimens of the 160 specimens exposed for 40 months to captive termite colonies in the laboratory were more severely damaged than the field-exposed specimens.

By the end of 2 years virtually all formulations containing dioctyladipate as the plasticizer at all exposure sites had become shrunken and embrittled, which effectively removed them from consideration in evaluating the exposure results. Of the remaining 240 specimens in Panama, 117 were damaged to some degree at the end of 75 months; 56 of these specimens contained no toxic additive. In Mississippi, 44 of the remaining 240 specimens in the field were damaged at the end of 60 months; 41 of these specimens contained no toxic additives. Of the remaining 120 specimens in the laboratory, 33 were damaged at the end of 40 months; 27 of these specimens contained no toxic additive.

(continued)

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Subterranean termites						
Tropical environments						
Tropical termites						
Electrical insulation						
Polyvinyl chlorides						
Toxicant						
Aldrin						
Dieldrin						
Lindane						
Termite resistant plastics						
Plasticizers						
o-TCP (tricresyl phosphate fortified with the ortho isomer)						
DOP—dioctyl phthalate						
DOA—dioctyl adipate						
TCP—tricresyl phosphate						
Plastic hardness						

Formulations plasticized with dioctylphthalate were the most heavily attacked, even when they contained a toxicant. In Panama, formulations plasticized with tricresyl phosphate fortified with the ortho isomer were the least damaged, either with or without toxicant present, although formulations plasticized with tri-p-cresyl phosphate were nearly as good. Conversely, in Mississippi, less attack was noted on the tri-p-cresyl phosphate than the tri-p-cresyl phosphate fortified with the ortho isomer. In Panama lindane was somewhat more effective and dieldrin least effective in preventing termite attack; aldrin more nearly matched lindane in this respect. No single toxicant was outstanding when compared to the other two, especially in Mississippi where there was little attack on any of the specimens containing toxicants at either exposure location.

CONTENTS

ABSTRACT

One phase of the investigation on the termite resistance of various experimental polymeric materials has been completed. Thirty-two formulations containing polyvinyl chloride resin were prepared incorporating, variously, four plasticizers and three toxicants. Of the 320 specimens exposed for 75 months in the Panamanian jungle, 135 specimens (42%) showed evidence of attack, ranging from light to heavy, although in general the attack was light; 79 specimens (25%) of the 320 specimens exposed for 60 months in the pine woods of Mississippi also showed evidence of attack, generally light. The 42 damaged specimens of the 160 specimens exposed for 40 months to captive termite colonies in the laboratory were more severely damaged than the field-exposed specimens.

By the end of 2 years virtually all formulations containing dioctyladipate as the plasticizer at all exposure sites had become shrunken and embrittled, which effectively removed them from consideration in evaluating the exposure results. Of the remaining 240 specimens in Panama, 117 were damaged to some degree at the end of 75 months; 56 of these specimens contained no toxic additive. In Mississippi, 44 of the remaining 240 specimens in the field were damaged at the end of 60 months; 41 of these specimens contained no toxic additives. Of the remaining 120 specimens in the laboratory, 33 were damaged at the end of 40 months; 27 of these specimens contained no toxic additive.

Formulations plasticized with dioctylphthalate were the most heavily attacked, even when they contained a toxicant. In Panama, formulations plasticized with tricresyl phosphate fortified with the ortho isomer were the least damaged, either with or without toxicant present, although formulations plasticized with tri-p-cresyl phosphate were nearly as good. Conversely, in Mississippi, less attack was noted on the tri-p-cresyl phosphate than the tri-p-cresyl phosphate fortified with the ortho isomer. In Panama, lindane was somewhat more effective and dieldrin least effective in preventing termite attack; aldrin more nearly matched lindane in this respect. No single toxicant was outstanding when compared to the other two, especially in Mississippi where there was little attack on any of the specimens containing toxicants at either exposure location.

PROBLEM STATUS

This is a final report on this phase of the problem.

AUTHORIZATION

NRL Problem G04-01
Project RR 104-03-41-5503

Manuscript submitted March 29, 1972.

TERMITE RESISTANCE OF POLYVINYL CHLORIDE PLASTICS IN SOUTHERN TEMPERATE AND TROPICAL ENVIRONMENTS

FINAL REPORT OF PHASE 1 — EFFECT OF PLASTICIZERS AND INSECTICIDES

INTRODUCTION

Damage to man's goods by the activity of termites has long been a problem in those regions where these animals abound. Much of this damage has military significance, such as that resulting from destruction of polymeric insulating materials used on communication lines and in electronic equipment. Consequently, under the sponsorship of the Naval Facilities Engineering Command, NRL has engaged in a program to investigate the nature of termite attack on such polymeric materials and to evaluate the performance of various experimental formulations. This program has been conducted in two phases; in the first phase experimental polyvinyl chloride (PVC) plastics in combination with various plasticizers and toxicants were studied, and in the second phase, which will be described elsewhere (1), non-PVC plastic materials have been studied with other experimental PVC formulations containing nontoxic additives.

Efforts made elsewhere to determine the susceptibility of various proprietary polymeric materials to termite damage have been impaired because of a lack of information concerning the chemical composition of these polymers. To correct this deficiency all polymers used in both phases of this study were prepared in the laboratory at NRL so that the chemical composition of each formulation was precisely known. It is hoped that termite activity can be correlated with the composition of these plastics and that a better understanding of the relationship between termite activity and these formulations will provide a basis for fabricating termite-resistant insulating materials.

The data presented here represent the cumulative results of termite attack on specimens of 32 PVC formulations exposed in the Panamanian jungle in December 1964, in the pine woods of Mississippi in November 1965, and in the laboratory of the U.S.D.A. Wood Products Insect Laboratory (WPIL) at Gulfport, Mississippi, in September 1965. Experimental details of the jungle exposure have been described in a preliminary report (2) and the results of the first 2 years of exposure in a subsequent report (3). Preliminary reports have also been issued in the Mississippi exposures (4-7). This phase of the program was terminated after 75 months by the removal of the remaining specimens from exposure in Panama in March 1971; the Mississippi exposure was terminated in November 1970 after 60 months.

EXPERIMENTAL PROCEDURE

Formulation Variables

The 32 PVC formulations used in this exposure incorporated, variously, four plasticizers, three toxicants, and two degrees of 'internal' hardness (8), as shown in Table 1. Subsequent exposure of these plastics has shown, however, that variability in hardness, achieved by increasing the amount of silica added to the formulations, was not sufficient to show a significant increase in termite resistance. Therefore, this variable will not be considered further in this report, and all of the data from the high-silica formulations will be combined with those from the low-silica controls.

Table 1
Composition of Polyvinyl Chloride Formulations

Formulation Number	Composition (Per Hundred Parts of Resin)*						
	Toxicants			Plasticizers			
	Aldrin	Dieldrin	Lindane	TCP	o-TCP (TCP Fortified with 30-wt-% Ortho Isomer)	DOP	DOA
1	—	—	—	100.0	—	—	—
2	1.3	—	—	100.0	—	—	—
3	2.6	—	—	100.0	—	—	—
4	—	1.3	—	100.0	—	—	—
5	—	2.6	—	100.0	—	—	—
6	—	—	1.3	100.0	—	—	—
7	—	—	2.6	100.0	—	—	—
8	—	—	—	100.0	—	—	—
9	—	—	—	—	100.0	—	—
10	1.3	—	—	—	100.0	—	—
11	2.6	—	—	—	100.0	—	—
12	—	1.3	—	—	100.0	—	—
13	—	2.6	—	—	100.0	—	—
14	—	—	1.3	—	100.0	—	—
15	—	—	2.6	—	100.0	—	—
16	—	—	—	—	100.0	—	—
17	—	—	—	—	—	100.0	—
18	1.3	—	—	—	—	100.0	—
19	2.6	—	—	—	—	100.0	—
20	—	1.3	—	—	—	100.0	—
21	—	2.6	—	—	—	100.0	—
22	—	—	1.3	—	—	100.0	—
23	—	—	2.6	—	—	100.0	—
24	—	—	—	—	—	100.0	—
25	—	—	—	—	—	—	100.0
26	1.3	—	—	—	—	—	100.0
27	2.6	—	—	—	—	—	100.0
28	—	1.3	—	—	—	—	100.0
29	—	2.6	—	—	—	—	100.0
30	—	—	1.3	—	—	—	100.0
31	—	—	2.6	—	—	—	100.0
32	—	—	—	—	—	—	100.0

*Each of the formulations contained the following components in pph: Geon 101 (B.F. Goodrich PVC resin) 100; silica (HiSil 303) 20 (50 for formulations 8, 16, 24, 32); carbon black (Pelletex) 2.0; whiting (Witcarb "R") 30.0; lead maleate (Trimal) 3.5; and dibutyltin laurate (Thermolite) 2.0. The latter two components act as stabilizers.

Plasticizers—Commercially available grades of dioctyl phthalate (DOP), dioctyl adipate (DOA), and tricresyl phosphate (TCP) were used as plasticizers. TCP was chosen as a plasticizer because experimental results (8) indicate that PVC plasticized with TCP resists termite attack better than PVC plasticized to a comparable hardness with DOP. The commercial preparation of TCP consists predominantly of the para isomer, but contains some of the ortho isomer. Although not shown specifically for termites, the general toxicity of the ortho isomer toward animal organisms suggests that the reported resistance of TCP may be attributed to the presence of the ortho isomer. To explore this point, TCP fortified with 30 wt-% of the ortho isomer (o-TCP) was used as the fourth plasticizer.

Toxicants—One potentially useful method of protecting termite-susceptible synthetic material is the addition to the formulation of a chemical agent which imparts a toxic or repellent quality to the finished product. Aldrin, dieldrin, and lindane have had prior trials as such agents in the formulation of termite-resistant PVC plastics. Results of the experiments, however, are inconclusive because of the uncertainty of the degree of retention of insecticide during the compounding process. Because of the close control exercised in the compounding of the present formulations, the effectiveness of these additives was reexamined. Separate weight-loss studies indicated that under the milling conditions used less than 1% of the added material was violatized.

The chief disadvantages associated with the use of toxicants as protective additives are that they limit the end use of the material, possibly lose their effectiveness over a period of time, and may create handling problems for personnel. Also, since the inception of this work, these polychlorinated organic insecticides have become implicated in environmental pollution and are considered a threat to the ecology of the areas in which they are used. These disadvantages provided the impetus to investigate the use of other nontoxic methods of obtaining termite-resistant plastics. The results of this investigation, which constitutes the second phase of this study, will be reported elsewhere.

Compounding Procedures

The various plastics were prepared by compounding the ingredients of the formulations on a roller mill operated at a temperature of 260° to 270°F. The initial mix for each formulation consisted of the resin, whiting, and plasticizer. After these constituents were blended, carbon black, lead maleate, dibutyltin laurate, and silica were added, in the order given. After thorough mixing of the charge, the rolls were adjusted to give a 50-mil clearance and the material was sheeted off. When a toxicants was part of the formulation, it was added to the mix just prior to sheeting so that it would receive a minimum exposure to heat. The total milling time for each charge was about 20 minutes; the milling time for the toxic additives was 5 minutes. The material, as it came from the mill, was sufficiently smooth and uniform to be used directly for preparing the specimens; the sheets were cut into 3-by-5-inch panels for later specimen fabrication.

Exposure Technique

The initial tropical exposure site was located on Galeta Island at the Atlantic end of the Panama Canal Zone. This test area has been used for various NRL termite exposure studies for the preceding 10 years. It has a fairly heavy jungle canopy and local environmental conditions conducive to termite activity. An analysis of the termite population in this area indicated that the predominant genus was *Heterotermes*, although *Coptotermes*, as reported earlier (2), has been known to be prevalent. A total of 320 plastic specimens (ten replicates each of the 32 PVC formulations) was placed on exposure in December 1964. The bed, shown in Fig. 1, was located on the crest of a small hill which provides good drainage. The specimens were randomly distributed throughout the bed.

Fig. 1—Polyvinyl chloride exposure bed located on the crest of a small hill which provided good drainage

Each specimen was secured around a 1-in.-diameter, 5-in.-long oak dowel by monel staples and PVC cement. Oak was chosen as a support for the specimens because of its attractiveness to termites. The open ends of the dowel were capped with metal plug buttons* as shown in Fig. 2. Initially, the specimens were buried vertically, 1 foot on center, with the top of each dowel about 1 in. below the ground line. During a subsequent inspection, however, the specimens were reburied so that about 1 inch of the dowel remained above the ground to facilitate the location of the specimens on future inspection. The exposure bed was seeded with 48 evenly distributed bare oak dowels to serve as bait and as indices of the termite activity in the area. The exposure beds were rebaited at each inspection with untreated, susceptible wood to retain an active termite population.

At the end of about 4 years of exposure, baitwood and specimen inspection indicated that the termite population at the exposure site had been drastically reduced. The cause of this decrease in activity was not determined unequivocally; however, it is suspected that the population was decimated by an influx of ants into the area. As a consequence, the exposure bed was relocated at the Navy's Gatun Tank Farm near Margarita, C.Z., in the spring of 1969. The termite activity in this area is quite good, with the genus *Heterotermes* predominating. At the new exposure site the specimens were arranged on the ground in the

*Plug buttons are small, multi-tined ferrous metal caps, which are used to cover openings in the chassis of electronic equipment.

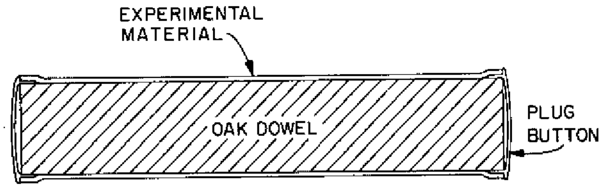


Fig. 2—A diagrammatic presentation of a typical exposure specimen

same relative position that they occupied in the original bed. Untreated pine panels were laid over the specimens as bait, and the entire bed was covered with about 1 inch of soil.

The Mississippi field exposure site (Fig. 3) was located in the Harrison Experimental Forest about 20 miles north of Gulfport. This test area has been used for various U.S.D.A. Forest Service termite exposure studies for several years. It has an overstory of longleaf pine and an understory of dogwood and other small trees. The termites are very active in the area, with *Reticulitermes flavipes* (Kollar) and *R. virginicus* (Banks) being the pre dominant species. A total of 320 plastic specimens (10 replicates each of the 32 PVC formulations) were placed on exposure in November 1965 (4).

Fig. 3—Polyvinyl chloride exposure bed located in the pine woods of the Harrison Experimental Forest

The forest litter was cleared down to mineral soil, and the specimens were randomly distributed on the soil throughout the bed. Each specimen was covered with a weighted (brick) 6-by-6-by-1-inch pine sapwood board to act as a food source for the termites. The presence of the board also acts as an indicator to determine if termites are in close proximity to the specimen in question. After the second annual inspection, the specimens were sandwiched between boards before being replaced on the ground.

Five samples of each formulation (160 total plastic specimens) were installed in a laboratory study (4) in Gulfport, Mississippi, in September 1965. The test was conducted in a stainless-steel tank 4 feet long by 2 feet wide by 1-1/2 feet deep, to which a heavily termite-infested pine log had been added, and filled with moist soil to a depth of 1 foot. The PVC specimens were sandwiched between 6-by-6-by-1-inch pine sapwood boards (Fig.

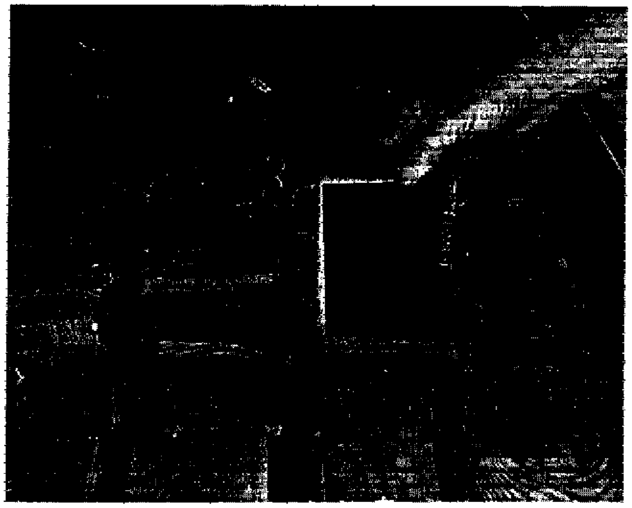


Fig. 4—Laboratory exposure tank containing the plastic specimens sandwiched between untreated pine boards and an active termite colony

4) and placed on top of the soil within the tank. A glass cover was placed on top of the tank to insure a high moisture content within the enclosure.

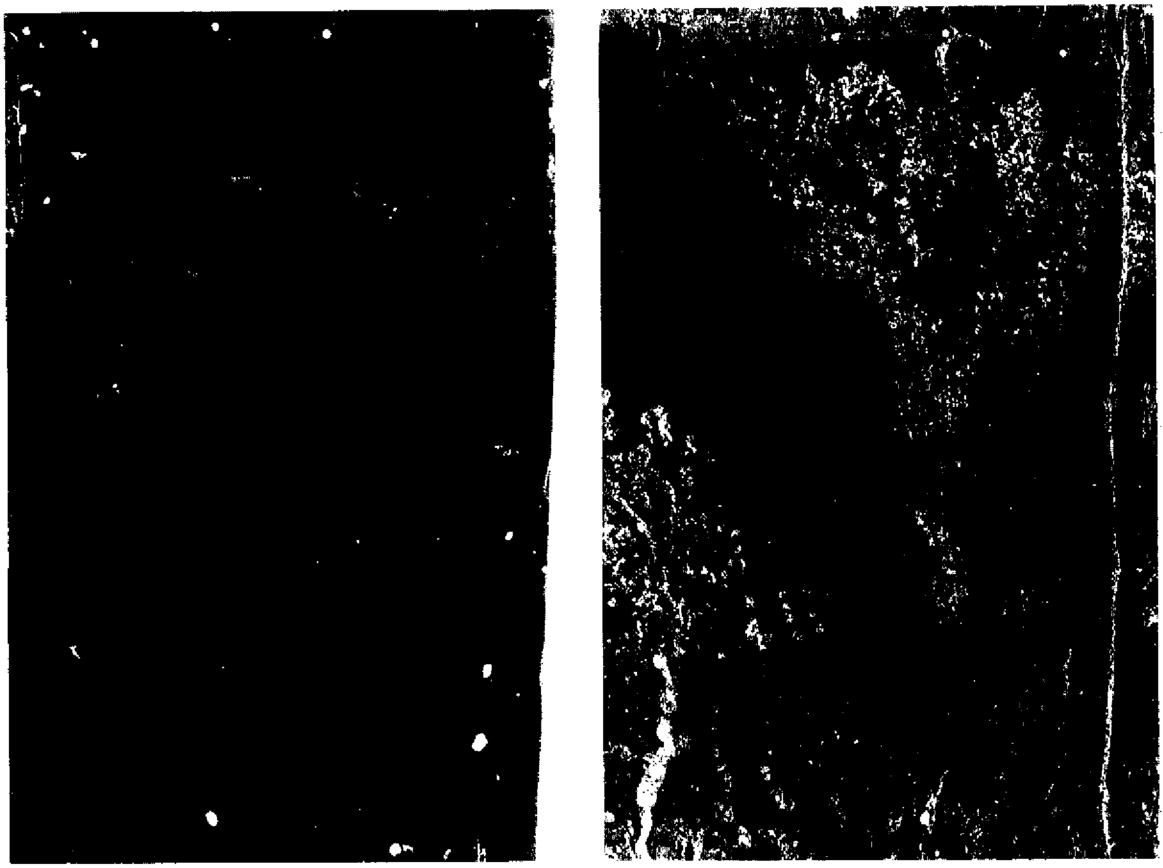
Rating System

The specimens are rated by visual inspection, according to the following numerical system:

0 — no visible termite damage to the plastic
1 — etching or very slight attack $\lesssim$ 5 mils
2 — termites cutting into the plastic to a depth of $\approx$ 5-20 mils
3 — termites cutting into the plastic to a depth of $\approx$ 20-35 mils
4 — termites cutting into the plastic to a depth of $\approx$ 35-50 mils
5 — perforation of the plastic (failure)

The ratings were performed by the same individuals throughout the course of the study.

A photograph of a heavily damaged specimen is presented in Fig. 5. This specimen, which contains DOP and the higher concentration of silica, has been perforated in several places for a rating of 5. Close scrutiny indicates that these perforations have been made from within the specimen. There is a rather deep channel cut in the plastic on the underside, one end of which terminates at a plug button. This channel was probably the main point of entry for the termites. In addition, two other lesser channels were observed which also lead to the edges of the specimen, between the tines of the plug buttons. When the specimen was removed, it contained live termites, and the supporting dowel was almost completely disintegrated.



(a) Front (b) Back

Fig. 5—Heavily damaged PVC panel showing eight penetrations and deep channeling

RESULTS AND DISCUSSION

The first full inspection of the jungle exposure bed was made in February 1966 (2), and the second inspection, representing 26 months of exposure was performed in February 1967 (3). At the fourth inspection in April 1969 (9), it was noted that the termite activity in the area had declined drastically as shown by virtually no infestation of termites in the baitwood in and around the exposure bed and by the decrease in the incidence of new attack on the specimens as compared to the previous year; only 2% of the specimens were attacked during the fourth year of exposure. Because of the need for long-term results to differentiate between the effectiveness of toxicant-plasticizer combinations and to determine the persistence of the toxicants in the plastics, the remaining specimens in the bed were relocated as described earlier. Subsequent inspections were performed on a yearly basis until March 1971, at which time the project was terminated.

The Mississippi field inspections were made on an annual basis starting in November 1966 (5), while the laboratory test was examined at 6-month intervals starting in June 1966. After the first 6-month inspection and the first annual inspection (6), it was necessary to recharge the tank with new termite colonies since termite mortality was occurring, no doubt caused by the insecticide in the specimens. The laboratory exposure of the specimens was closed after 48 months; the field exposure after 60 months. The results of the final ratings from all the sites constitute the input to this report.

Those formulations containing DOA began to show signs of physical hardening during the early part of the exposure period (2,6). In Panama this hardening was accompanied in most cases by a shrinkage of the specimens on the supporting dowels with attendant cracking and a change in the coloration of the plastics from black to various shades of grey. The initial hardness value of these formulations (Shore A durometer) was 63; at the termination of the exposure the hardness was estimated to be about 60 (Shore D durometer). Similar results were obtained when these DOA-containing formulations were exposed to the marine environment (10), and in both cases the increase in hardness of the specimens is attributed to a loss of plasticizer. The lightening of the specimens suggests that carbon black was carried along by the leaching DOA; it is reasonable to presume that other nonreactive constituents of these formulations were carried along as well. Almost all of the damage incurred by these formulations had taken place in Panama by the 1967 inspection and in Mississippi by the 1968 inspection; continued hardening of the plastics prevented further damage. At the termination of the Panama exposure all of the DOA-containing specimens had undergone hardening and shrinkage. This hardening of the DOA-containing plastics became an overriding factor in protecting these specimens from subsequent damage. Because of this masking effect, the exposure data derived from these specimens have not been included when making comparisons with other formulation variables.

Of the 320 specimens exposed in Panama, 135 have sustained some degree of attack ranging from very slight to complete penetration of the plastic. Of this number 79 had been attacked by the end of 2 years (3) and 109 at the end of 4 years, at which time the bed was relocated. Attack was lighter in the Mississippi field studies with only 79 of 320 specimens sustaining some degree of attack. Of these, 71 had been attacked by the end of 2 years. The general distribution of attack for the entire exposure period of 75 months in Panama is presented in Table 2, which shows the location in the bed of each damaged specimen, the amount of damage, and the formulation number. From this table it can be seen that termite activity among the plastic specimens has been reasonably uniform both in terms of distribution and degree of attack, except that six of the 12 specimens perforated were located in the lower, middle portion of the bed. From inspection of Tables 3 and 4, it can be seen that the general level of attack was not high. In only three instances in Panama and one instance in Mississippi was every specimen of a given formulation damaged. Conversely, at the former site all the specimens of six formulations remained in an undamaged state; however, two of these were DOA-containing formulations whose progressive increase in hardness with exposure precluded further termite damage after about the first 2 years. In Mississippi all specimens of 17 formulations remained undamaged. A special consideration should be given those specimens with an attack rating of 1; such rating may only reflect an exploratory nibbling by the animals which discouraged them from further activity, rather than indicate a real susceptibility of the plastic. This point can not be emphasized too strongly. A comparison of the relative contribution of each of the formulation variables to the resistibility of the plastics to termite damage is presented in Tables 5 and 6. The results of those plastics containing DOA as the plasticizer represent the first 2 years of exposure only.

From the complete results of the final inspections presented in Tables 3 and 4 and from the summarized comparisons in Tables 5 and 6, it is evident that as reported previously (3,11) the nature of the plasticizer (excluding DOA and formulations containing toxicants) did not contribute appreciably to the resistance of the plastics. Again, when both frequency and intensity of attack are considered in the Panama exposure (Table 3),

Table 2
Termite Activity as a Function of Specimen Location and Formulation
(Exposed Period 75 Months)

Row Location in the Bed	Column Location in the Bed															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	*	16-3		16-3	18-3	26-2		16-3				16-2				20-2
2	5-2†	7-1			17-4	9-1		1-2	21-1	18-1		8-2	16-1		24-2	
3		19-1		28-2		20-2	25-5	22-1	24-3	17-3				17-2	18-1	
4	30-2	25-1		16-3	25-3	10-1	4-1	13-1			32-2		12-1	22-2		
5			16-2	18-3	21-3								24-3	6-1	20-2	
6						9-1	6-1								24-5	17-5
7	16-1		1-3		9-2								16-1			20-2
8			32-2	19-1			23-1							8-2	20-2	10-1
9		26-2	1-3					25-2		20-1			22-1	19-1	9-2	
10						19-2		20-3			21-1		5-1		17-3	
11		20-1	2-1				1-3			10-1	9-2				10-1	17-3
12					19-1									18-1		
13		25-2	10-1	8-1			9-1		9-3	19-1						4-1
14	9-3					18-1		4-1		24-2	22-2		24-1		10-1	
15		2-1	8-2				9-5			13-1					6-1	20-2
16	17-5						13-1			24-5			18-1		25-1	1-3
17	17-3	8-1	2-1	30-2					24-5	18-1				18-1		
18	24-3				1-3		4-3		21-1	25-2	8-3	24-2		8-3		
19		29-1					5-1	17-5	1-4	21-3		21-1			8-5	17-5
20		1-3	21-1	25-3	28-3	25-5	22-1	21-1		1-3		1-5				

*Blank spaces indicate the location of specimens that did not sustain any damage.
†Example: Formulation 5 (from table 1), attack rating 2.

Table 3
Attack Rating of Each Specimen as a Function of Formulation
(Panama)

No.	Formulation	Panel Ratings	No. Specimens Attacked*	Cumulative Rating†
1	TCP, LoSil‡	2 3 3 3 3 3 3 3 4 5	10	32
8	TCP, HiSil §	1 1 2 2 2 3 3 5	8	19
2	TCP, 1.3%A¶	1 1 1	3	3
3	TCP, 2.6%A		0	0
4	TCP, 1.3%D**	1 1 1	3	3
5	TCP, 2.6%D	1 1 2	3	4
6	TCP, 1.3%L††	1 1 1	3	3
7	TCP, 2.6%L	1	1	1
9	o-TCP, LoSil	1 1 1 2 2 2 3 3 5	9	20
16	o-TCP, HiSil	1 1 1 2 2 3 3 3 3	9	19
10	o-TCP, 1.3%A	1 1 1 1 1 1	6	6
11	o-TCP, 2.6%A		0	0
12	o-TCP, 1.3%D	1	1	1
13	o-TCP, 2.6%D	1 1 1	3	3
14	o-TCP, 1.3%L		0	0
15	o-TCP, 2.6%L		0	0
17	DOP, LoSil	2 3 3 3 3 4 5 5 5 5	10	38
24	DOP, HiSil	1 2 2 2 3 3 3 5 5 5	10	31
18	DOP, 1.3%A	1 1 1 1 1 1 1 2 3	9	12
19	DOP, 2.6%A	1 1 1 1 1 2	6	7
20	DOP, 1.3%D	1 1 2 2 2 2 2 2 3	9	17
21	DOP, 2.6%D	1 1 1 1 1 1 3 3	8	12
22	DOP, 1.3%L	1 1 1 2 2	5	7
23	DOP, 2.6%L	1	1	1
25	DOA‡‡, LoSil	1 1 2 2 2 3 3 5 5	9	24
26	DOA, 1.3%A	2 2	2	4
27	DOA, 2.6%A		0	0
28	DOA, 1.3%D	2 3	2	5
29	DOA, 2.6%D	1	1	1
30	DOA, 1.3%L	2 2	2	4
31	DOA, 2.6%L		0	0
32	DOA, HiSil	2 2	2	4

*Specimens attacked out of a total of 10 replicates per formulation.
†Maximum rating is 50.
‡LoSil—20 pph silica in formulation (basic formulation).
§HiSil—50 pph silica in formulation (combined with basic formulation).
¶ A—Aldrin.
** D—Dieldrin.
†† Lindane.
‡‡Almost all of the damage to the DOA specimens had occurred by the 1967 rating; continued hardening of the plastic prevented further damage.

Table 4
Attack Rating of Each Specimen as a Function of Formulation
(Gulfport, Miss. Field)

No.	Formulation	Panel Ratings	No. Specimens Attacked*	Cumulative Rating†
1	TCP, LoSil‡	1 1 1 1 2 4 5	7	15
8	TCP, HiSil§	1 1 3	3	5
2	TCP, 1.3%A¶		0	0
3	TCP, 2.6%A		0	0
4	TCP, 1.3%D**		0	0
5	TCP, 2.6%D		0	0
6	TCP, 1.3%L††		0	0
7	TCP, 2.6%L		0	0
9	o-TCP, LoSil	1 1 1 1 4 5 5 5 5	9	28
16	o-TCP, HiSil	1 1 1 1 1 1 3	7	9
10	o-TCP, 1.3%A		0	0
11	o-TCP, 2.6%A	1 1	2	2
12	o-TCP, 1.3%D		0	0
13	o-TCP, 2.6%D		0	0
14	o-TCP, 1.3%L		0	0
15	o-TCP, 2.6%L		0	0
17	DOP, LoSil	1 1 1 1 4 5 5 5 5	9	28
24	DOP, HiSil	1 1 1 3 4 5	9	15
18	DOP, 1.3%A		0	0
19	DOP, 2.6%A		0	0
20	DOP, 1.3%D	1	1	1
21	DOP, 2.6%D		0	0
22	DOP, 1.3%L		0	0
23	DOP, 2.6%L		0	0
25	DOA‡‡, LoSil	1 1 3 3 4 4 5 5 5 5	10	36
26	DOA, 1.3%A	1 1 1 1 1	5	5
27	DOA, 2.6%A	1 3	2	4
28	DOA, 1.3%D	1 1 1 3 3 3 3 5	8	20
29	DOA, 2.6%D	1 1 1	3	3
30	DOA, 1.3%L	1	1	1
31	DOA, 2.6%L		0	0
32	DOA, HiSil	1 1 1 4 5 5	6	17

*Specimens attacked out of a total of 10 replicates per formulation.
†Maximum rating is 50.
‡LoSil—20 pph silica in formulation (basic formulation).
§Hi-Sil—50 pph silica in formulation (combined with basic formulation).
¶A—Aldrin.
**D—Dieldrin.
††L—Lindane
‡‡Almost all of the damage to the DOA specimens had occurred by the 1968 rating; continued hardening of the plastic prevented further damage.

Table 5
Summary of Termite Activity in Relation to the Formulation Variables
(Panama)

Pertinent Component	Specimens Damaged		Average Rating of Damaged Specimens	Specimens Perforated	Remarks
	Number	Cumulative Rating			
Comparison of Plasticizers					
o-TCP	18/20*	39	2.2	1	Formulations containing toxicants not included
TCP	18/20	51	2.8	2	
DOP	20/20	69	3.5	7	
DOA	11/20	28	2.5	2	First 2 years only
Comparison of Toxicants					
Aldrin	24/60	32	1.3	0	For each toxicant, the two concentrations were combined (excludes DOA formulations)
Dieldrin	27/60	40	1.5	0	
Lindane	10/60	12	1.2	0	
None	56/60	167	3.0	10	Includes high and low silica with three plasticizers (excludes DOA formulations)

*Example: 18 specimens attacked out of 20 exposed.

Table 6
Summary of Termite Activity in Relation to the Formulation Variables
(Gulfport, Miss.—Field)

Pertinent Component	Specimens Damaged		Average Rating of Damaged Specimens	Specimens Perforated	Remarks
	Number	Cumulative Rating			
Comparison of Plasticizers					
o-TCP	16/20*	37	2.3	4	Formulations containing toxicants not included.
TCP	10/20	20	2.0	1	
DOP	14/20	43	3.0	5	
DOA	16/20	54	3.3	6	First 2 years only.
Comparison of Toxicants					
Aldrin	2/60	2	1.0	0	For each toxicant, the two concentrations were combined (excludes DOA formulations)
Dieldrin	0/60	0	0	0	
Lindane	0/60	0	0	0	
None	40/60	100	2.6	10	Includes high and low silica with three plasticizers (excludes DOA formulations)

*Example: 16 specimens attacked out of 20 exposed.

the presence of TCP fortified with the ortho isomer in the formulations continues to show a somewhat lower susceptibility to attack with a cumulative rating of 39 (100 maximum-combined silica data) as compared to 51 for TCP and 69 for DOP. This relative order provides a degree of correlation between the reported inherent toxicity of TCP (8) and the amount of damage sustained by the plastics. As before, specimens plasticized with DOP showed the least resistance to termite damage. Surprisingly, this greater susceptibility of the DOP-containing specimens to attack was still evident even in those formulations containing toxicants. A total of 38 of the 60 specimens containing both DOP and a toxicant were damaged to some extent compared with 13 for TCP- and 10 for o-TCP-toxicant combinations.

Those formulations containing toxic additives (DOA excluded) were much less heavily attacked than those that did not, as shown in Tables 3 and 4. Generally speaking the higher concentration of toxicant provided the greater protection; however, this difference was not large and the results from the two toxicant concentrations have been combined in each case for comparative purposes in Tables 5 and 6. In the jungle all of the six formulations containing dieldrin suffered some attack, although generally light (Table 3). Of the 60 specimens containing this toxicant 27 were damaged, for a cumulative rating of 40 (300 maximum). Aldrin performed better in that 24 specimens were damaged for a cumulative rating of 28, and two formulations containing aldrin at the highest concentration (2.6%) were not damaged at all. Lindane, however, provided the best protection of the three toxicants, although not appreciably better. Of the 60 specimens containing this material only 10 sustained damage for a cumulative rating of 12, two formulations containing the toxicant were not damaged at all, and two others had only one specimen damaged, each with a rating of 1. It should also be mentioned that during the first 2 years of the exposure when the DOA-containing plastics were still vulnerable to termite attack, both aldrin and lindane at the higher concentrations afforded complete protection.

As shown in Table 4, while the nature of the plasticizer (DOA excluded) exerted little influence, all of the insecticides were very effective in protecting the plastics in the Mississippi field exposure, except for those specimens containing DOA as the plasticizer. During the 2 years prior to the onset of hardening of these formulations, the presence of insecticide was not as effective in preventing termite damage, particularly in those formulations containing dieldrin. Eleven of these specimens were damaged, including one perforation.

An apparent decrease in effectiveness of the toxicants occurred in Panama when they were incorporated into the DOP-containing plastics as compared to their behavior in the other plastic formulations (Table 7). Although the presence of insecticide greatly decreased the percent of specimens attacked in each case as compared to the noninsecticide formulations, the cumulative rating for those panels containing DOP was still much higher than for those containing the other two plasticizers. If insecticide had been the dominant factor in conferring protection to the plastics, it should have been equally protective in the case of those formulations containing DOP. Results from nontoxic formulations suggest that o-TCP may have an inherent protective quality. Results from the toxic formulations further suggest that this quality does exist and that it is considerably enhanced by the presence of insecticide, while the behavior of the DOP-containing plastics is in response to only one stimulus, the insecticide. Further study would have to be made to determine if this fortifying relationship between o-TCP and insecticide is synergistic.

In the earlier report (3) it was speculated that the effectiveness of lindane may have been due to its vapor pressure which is considerably higher than that of the other two

Table 7
Interaction Between Plasticizer and Insecticide (Panama)

Plasticizer	No Insecticide Present				Insecticide Present			
	Specimens Attack (20 Maximum)	Percent of Max	Cumulative Rating (100 Maximum)	Percent of Max	Specimens Attack (60 Maximum)	Percent of Max	Cumulative Rating (300 Maximum)	Percent of Max
o-TCP	18	90	39	39	10	17	10	3
TCP	18	90	51	51	13	22	14	5
DOP	20	100	69	69	38	63	56	19

toxicants. It was supposed that there could be a sufficient concentration of this material in the vapor phase along the outer surface of the plastic to act as a repellent, thereby discouraging the organisms from making even exploratory nibbles. Theoretically, such a high vapor pressure would tend to deplete the reserve of lindane in the plastic and an increase in attack rate should be observed with time. In 1967 only two lindane (1.3 pph) specimens were attacked in Panama; after 4 additional years of exposure this number had risen to ten (eight at the lower concentration) of which only two specimens had a rating of 2; none were higher. This increase in attack on the lindane-containing specimens could be construed as an indication of a loss of lindane; however, if this is true, the loss is not great and the general efficiency of this toxicant is still quite high after a total of 75 months of jungle exposure.

To estimate more accurately the presence of residual insecticide in the jungle-exposed plastics, specimens containing aldrin or lindane at the higher concentration were sent to WPIL for assay in the laboratory using captive colonies of *Reticulitermes*. After 45 days, all termites exposed to the aldrin-containing plastics had died and only a very few termites were left in those colonies exposed to the lindane-containing plastics, and these expired subsequently. In neither case did the plastic sustain any termite damage during this exposure period. The results indicate the persistence of these chemicals when incorporated into a plastic matrix. Also indicated is the fact that these animals were killed by a lethal concentration of the insecticides in the vapor phase, which means that in the field these chemicals are continually leaving the plastic matrix by outward diffusion and vaporization. This action will ultimately exhaust the reservoir of these materials in the plastic. Since these plastics have not yet been depleted of the insecticides, the slowness of this diffusion process is indicated. However, the lifetime of these materials in the plastic is finite. This disadvantage would not be expected to occur in the case of the inert fillers which are being tested in the second phase of this study.

In many respects the results from the laboratory exposure did not reflect those from the field. Admittedly, this exposure was much more severe since the termites were held captive in the exposure tank at a population density much higher than that normally encountered in the field, and as they died out, the tank was recharged with new colonies. As shown in Table 8, the majority of the laboratory specimens were either not damaged at all or they sustained maximum damage. Three of the four damaged o-TCP-containing specimens were perforated; five of the six damaged TCP-containing specimens were perforated, and all seven of the damaged specimens containing DOP were perforated. As in the field tests, the presence in the formulations of TCP fortified with the ortho isomer continues to show a somewhat lower susceptibility to attack with a cumulative rating of 16 (50 maximum-combined silica data) as compared to 29 for TCP and 35 for DOP. Those formulations containing toxic additives (DOA excluded) were also much less heavily attacked than they were in either of the field exposures with only six out of 90 specimens damaged. Surprisingly, the lone failure among this group of plastics was a specimen containing lindane, which had performed excellently in the field exposures.

Table 8
Summary of Termite Activity in Relation to the Formulation Variables
(Gulfport, Miss.—Laboratory)

Pertinent Component	Specimens Damaged		Average Rating of Damaged Specimens	Specimens Perforated	Remarks
	Number	Cumulative Rating			
Comparison of Plasticizers					
o-TCP	4/10*	16	4.0	3	Formulations containing toxicants not included
TCP	6/10	29	4.8	5	
DOP	7/10	35	5.0	7	
DOA	10/10	48	4.8	8	First 2 years only
Comparison of Toxicants					
Aldrin	0/30	0	0	0	For each toxicant, the two concentrations were combined (excludes DOA formulation)
Dieldrin	4/30	6	1.5	0	
Lindane	2/30	6	3.0	1	
None	17/30	80	4.6	15	Includes high and low silica with three plasticizers (excludes DOA formulations)

*Example: 4 specimens attacked out of 10 exposed.

SUMMARY

Although the general level of attack on the PVC formulations has not been very great, enough activity has occurred to allow certain inferences to be made. As a consequence of the extensive hardening which occurred in those formulations containing DOA and which provided overwhelming protection against termite attack, exposure results from these plastics had to be discarded. Dioctylphthalate did not prove to be a desirable plasticizer to use in formulating polyvinyl chloride plastics where termite damage is possible. Plastics containing this plasticizer were susceptible to termite damage in the jungle, and even the presence of the toxic additives was insufficient to prevent a moderate amount of damage from occurring to many of the specimens during the exposure period. Plastics containing o-TCP as the plasticizer benefitted by an inherent protective quality possessed by this material; this quality was enhanced by the presence of insecticide in the formulations.

Those plastics containing toxicants have consistently undergone the least amount of attack. With respect to the jungle exposure, dieldrin was the least effective additive; some specimens of all the formulations containing this toxicant were damaged to some extent. Aldrin was more effective in the jungle; it provided complete protection at the higher concentration to formulations in two of the three plasticizer groups (DOA excluded). The performance of lindane was slightly better; this toxicant was also able to provide complete protection to two formulations and was the most effective additive in conferring a degree of protection to those plastics containing DOP. Although the number of lindane-containing specimens attacked increased with the passage of time, there was no evidence to support the earlier supposition that this material was superior because of its higher vapor pressure. After 75 months in Panama, exposed specimens plasticized with DOP and containing aldrin or lindane were still lethal to *Reticulitermes* colonies in the laboratory. With respect to the Mississippi exposure, all the toxicants were equally effective in conferring protection to the plastics, except for those specimens containing DOA. In this case the insecticides were not quite as effective, particularly dieldrin. While still vulnerable to attack, plastics containing this toxicant were the most heavily damaged, with one specimen perforated.

ACKNOWLEDGMENTS

The authors thank Mr. Ralph Taylor of the Chemistry Division of NRL who provided many valuable comments and suggestions during the preliminary stages of this project and Mr. Harry Nash of the Chemistry Division of NRL who supervised the fabrication of the plastics. Finally, the authors particularly extend thanks to Dr. John M. Leonard of the Ocean Sciences Division of NRL who has been closely associated with this work since its inception and who has contributed many valuable ideas and suggestions.

REFERENCES

1. C.R. Southwell, J.D. Bultman, and R.H. Beal, "Termite Resistance of Polymeric Materials, Phase 2—Nontoxic Polymers," NRL Report 7418, July 1972.
2. J.D. Bultman, J.M. Leonard, and C.R. Southwell, "Termite Resistance of Polyvinyl Chloride Plastics," NRL Memorandum Report 1704, June 1966.
3. J.D. Bultman, J.M. Leonard, and C.R. Southwell, "Termite Resistance of Polyvinyl Chloride Plastics—Two Years' Exposure in the Tropics," NRL Report 6601, Oct. 1967.
4. R.H. Beal and K.E. Tynes, "Testing of Wire Insulating Materials for Resistance to Termites," Establishment Report, U.S.D.A. Wood Products Insect Laboratory, Gulfport, Mississippi, June 1966.
5. R.H. Beal and K.E. Tynes, "Testing of Wire Insulating Material for Resistance to Termites," First Annual Field Progress Report, U.S.D.A. Wood Products Insect Laboratory, Gulfport, Mississippi, Jan. 1967.
6. R.H. Beal and K.E. Tynes, "Testing of Wire Insulating Materials for Resistance to Termites," Third Semiannual Laboratory Progress Report Supplement 1, U.S.D.A. Wood Products Insect Laboratory, Gulfport, Mississippi, July 1967.

7. R.H. Beal, "Testing of Wire Insulating Materials for Resistance to Termites," Progress Report Supplement 1, U.S.D.A. Wood Products Insect Laboratory, Gulfport, Mississippi, Jan. 1968.

8. F.J. Gay and A.H. Wetherly, "Laboratory Studies of Termite Resistance IV. The Termite Resistance of Plastics," Commonwealth Scientific and Industrial Research Organization, Division of Entomology Technical Paper 5, 1962.

9. C.R. Southwell and J.D. Bultman, NRL Letter Report 9655 dated Dec. 5, 1969.

10. J.D. Bultman and C.R. Southwell, "An Investigation of Marine Borer Resistance of Polymeric Materials," NRL Report 7343, Dec. 1971.

11. R.H. Beal, "Testing of Insulating Materials for Resistance to Termites," Final Progress Report, U.S.D.A. Wood Products Insect Laboratory, Gulfport, Mississippi, Sept. 1971.