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Progress in the Study of Anti-Fouling Compositions for the Protection of Flying Boat Hull Bottoms

NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

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NAVY DEPARTMENT

Report on
Progress in the Study of
Anti-Fouling Compositions for the Protection
of Flying Boat Hull Bottoms

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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TABLE OF CONTENTS

Page

INTRODUCTION

METHODS

CONCLUSIONS AND RECOMMENDATIONS

Appendix A

Appendix B

Appendix C

Page

INTRODUCTION

METHODS

CONCLUSIONS AND RECOMMENDATIONS

Appendix A

Appendix B

Appendix C

INTRODUCTION

(a) Authorization

1. This study was authorized by Project Order 32-40 of 29 June 1941.

(b) Statement of Problem

2. The subject of this study may be stated briefly as the development of a compatible system for the protection of flying boat hull bottoms and pontoons. Previous reports on this subject have outlined the detailed requirements and only reference to them will be made here. In a recent report, "A Preliminary Study of Resins and Poisons to Determine Their Applicability to Anti-Fouling Compositions," (Naval Research Laboratory Report #P-1680, dated 6 January 1941) detailed requirements pertinent to the successful solution of the problem of the fouling of aircraft hull bottoms are outlined. In addition, this report describes considerable experimental work which has been conducted in this Laboratory on the individual properties of various resins, resin combinations and toxicants to form some basis of selection for the more adaptable compositions to anti-fouling purposes. The motive of the present study is to describe the formulation of various possible anti-fouling coatings and to describe their effectiveness as fouling repellents. Furthermore, the effect of any ingredient upon the metallic aluminum composing the hull of the ship is studied to prevent the recommendation of a product for use in service which might possibly prove more detrimental to the life and efficiency of the hull than do barnacles themselves.

3. Considerable investigative work has been done on the effect of various toxicants upon marine growth, and also the behavior of nearly all types of paint vehicles subjected to submarine exposure have been studied. During this investigation, considerable thought and effort have been directed to the problem of combining the most effective fouling repellent with the most stable and impervious film-forming material to produce a coating of optimum performance in both respects.

(c) Known Facts Bearing on the Problem

4. The problem at hand varies widely from the old and as yet incompletely solved problem of the protection of ships' hulls from marine fouling. Since a flying boat moves through the water at such high speeds while taking off and landing, prime requisites for the condition of the surface of its hull are that it be hard, smooth, and highly resistant to abrasion. The anti-fouling qualities should be added without subtracting these properties from existing formulations. Also of paramount importance is the necessity for safeguarding the thin gauge aluminum metal from any attack by the active ingredients of the paint.

5. The toxicants and film-forming substances most adaptable to this type of composition have been studied and reported in the report referenced in paragraph 2. With the results of this report in mind, the formulations included herein have been made and exposed for evaluation.

(d) Narrative of Original Work at this Laboratory on the Problem

6. Directly concerned with the protection of hull bottoms of flying boats, this Laboratory has written several reports on special phases of the problem. As suggested in the original authorization, a report was written on "The Characteristic of Petroleum Thinners Available Commercially for Organic Protective Coatings," designated as Naval Research Laboratory Report #P-1532 and dated 11 May 1939. This report discusses at length methods available for the determination of the aromaticity of hydrocarbon mixtures. Furthermore, the exact characteristics of a number of thinners used extensively in hull bottom finishes are summarized, from which summary the thinners most adaptable for use with special compositions might be determined. Another report designated as Naval Research Laboratory Report #P-1555 on "The Microscopic Examination of Zinc Chromate Primers" and dated 24 August 1939 records further information dealing with the characteristics of zinc chromate primers formulated according to Navy Aeronautical Specification P-27b. This primer or a more adaptable modification is almost unanimously accepted as a prerequisite to any top coat for aircraft finishing, whether for hulls or above-water surfaces. A third and perhaps fuller report bearing more directly on the subject is Naval Research Laboratory Report #P-1680 on "A Preliminary Study of Resins and Poisons to Determine Their Applicability to Anti-Fouling Compositions" dated 6 January 1941. In this report is recorded much of the experimental evidence on which a considerable number of the formulations included herein are based.

7. In addition to these reports concerned directly with flying boat hull protection, this Laboratory has written Naval Research Laboratory Report #P-1299 on "Moravian Green Anti-Fouling Paint - the Inorganic Components" dated 18 August 1936. This report includes an analysis of the inorganic constituents which had proven quite effective as fouling repellents a few years previously. This report was followed by another -- Naval Research Laboratory Report #P-1321 dated 27 October 1939, "The Analysis of Moravian Green Anti-Fouling Paint; the Individual Compounds, the Inorganic Material, and the Percentage Composition." The various effective poisons are identified and also the relative amounts of each are indicated. On the basis of this analysis, a new paint was prepared from various constituents and it appeared to possess the same qualities as exhibited by the original Moravian green formula. Although these latter two reports deal exclusively with an anti-fouling composition designed for surface ship hulls alone, much general information on the subject is included which is of practical application in the formulation of similar coatings for aircraft.

METHODS

(a) Materials

8. Proprietary Products. The paint industry at large was invited by letter to submit their recommendations and samples of their products for evaluation as anti-fouling coatings. The response to this invitation was disappointingly small. Only five manufacturers were willing to submit samples of their product, and these were put on exposure along with other experimental materials going forward for tests. Another proprietary paint,

marketed under the name of Mur-Cop, was procured and used partially as a control, due to the fact that its effectiveness as an anti-fouling coating is fairly well recognized among operators of small pleasure craft; however, it possesses physical properties such as inadequate drying, a very highly corrosive nature, and extreme softness, which eliminate this product as a coating for aluminum hulls of flying boats.

9. Experimental Coatings from Other Laboratories. Two suppliers of paint manufacturers' raw material who maintain excellent staffs to prosecute research problems in the coatings field willingly agreed to cooperate in the solution of this problem. The Goodyear Tire and Rubber Company of Akron, Ohio, prepared a number of materials and submitted them for evaluation at the Naval Research Laboratory. Likewise, personnel from the staff of the Bakelite Corporation have been vigorously engaged in the study of the fouling problem. In both instances, the Laboratory has supplied metal panels on which the manufacturers have applied their formulations which were subsequently returned to the Laboratory for exposure and evaluation under identical conditions as experimental coatings formulated here. The Bakelite Corporation has furnished complete formulae on all samples submitted and their personnel have frequently consulted with Laboratory personnel throughout the entire investigation.

10. Poisons. Many salts of the heavy metals have been studied as fouling repellents. Compounds of copper and mercury, particularly when used in combination, have been found to be among the most effective of the numerous inorganic substances examined. Salts of these metals have been studied in this investigation and have been found quite superior in their effectiveness.

11. In addition to the metal salts which have been considered for so long, numerous manufacturers of chemicals in industry were invited to submit samples of their products obtainable in commercial quantities which possess possible merit as fouling repellents. The nature and source of these chemicals are designated at the point of their occurrence throughout the tables of data in this and subsequent reports.

12. Resins and Vehicles. No less important than the choice of an effective anti-fouling agent is the selection of a resin combination to carry this agent in the paint film, and to release it at the optimum rate for the most successful fouling inhibition. Factors to be considered in the selection of such a vehicle include its permeability to water and solutions, its resistance to deterioration during long contact with water, adhesion, toughness, abrasion resistance, and general durability as a paint film. If the film containing the anti-fouling agent is too impervious to water, even the smallest concentrations of the poisons do not become available and the marine organisms are able to establish themselves on the paint film. On the other hand, the film should not be so permeable such as to permit the rapid extraction of all of the poisons in a relatively short time, making them available at a much faster rate than is necessary.

13. To determine the effectiveness of numerous resin combinations, a considerable number of different type resins in several mixtures were

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13. To determine the effectiveness of numerous resin combinations, a considerable number of different type resins in several mixtures were

studied. These included chlorinated rubber, acrylic polymer, pure phenolics, alkyds, and nitrocellulose, individually and in numerous combinations. The pure phenolics represent the hardest and most impervious group, although the chlorinated rubbers are quite impermeable. Nitrocellulose films are hard, but very permeable, and possess rather poor water resistance. Nitrocellulose was used primarily as a modifying agent for other resins. The water resistance of the alkyds is only fair, and these materials were used to best advantage as modifying agents for harder and more impervious film-forming products. The acrylic polymers cover a substantial range of hardness and permeability. One of the harder polymers modified with a hard phenolic and plasticized with dibutyl phthalate was found quite effective for dispelling the included poison at the most effective rate.

(b) Experimental

14. For the preparation of all the formulations studied, a small quart-size porcelain ball mill was employed. Most grinds were allowed to run for 24 hours, as this was found sufficient usually to completely disperse the type of pigments used. In most instances, the active ingredients (anti-fouling agents) were added directly to the mill and allowed to grind the entire period.

15. In all the tests for the evaluation of these finishes, anodized panels of 24ST aluminum alloy were used. For making the submarine exposure tests, panels size 7" x 11" were prepared which had a riveted seam down the center. In the beginning of the first series of tests, 2S aluminum rivets were included, but due to their susceptibility to corrosive influences, their use was discontinued in favor of A17ST aluminum alloy rivets. These rivets are to be employed in all future exposure panels.

16. Submarine Exposure. The system of preparing exposure panels for evaluation in environments favorable to fouling varied but little from one formulation to another. Before riveting, the smaller (4" x 12") panels were given a light coating of zinc chromate (P-27b) primer in order that some anti-corrosive agent be included under the seam. This initial coat was then followed with a second just a few hours before the first of the succeeding top coats was applied. In preparing the majority of materials included in the three series reported herewith, two coats of anti-fouling formulation were applied directly over the second priming coat. In some instances it was found advisable to include an impervious or sealing film between the top coats of anti-fouling paint and the zinc chromate primer. Subsequent experience has justified this technique and sealer coats are now being employed in almost all systems.

17. The Bureau of Aeronautics arranged with the Naval Air Stations at San Juan, Puerto Rico, and at Guantanamo Bay, Cuba, to expose these panels and to examine them and submit reports on their condition at the end of each month. The Laboratory made a contract with the Sub-Tropical Testing Service at Miami, Florida, to conduct similar tests at their station.

18. Triplicate panels of each material studied are prepared as described above, and one panel of the same material is exposed at each of

these three stations. The monthly reports from each station are returned to the Naval Research Laboratory (those from the Naval Air Stations by way of the Bureau of Aeronautics) where they are assembled and correlated with each other and with exposure data pertinent to the value of the paint.

19. The Florida test station of the Sub-Tropical Testing Service is located about 15 miles south of Miami in a small inlet at Tahiti Beach. Their racks are extended several hundred yards into the Bay and the panels are suspended from these racks to a depth of about 4 feet below low tide. They are allowed to swing freely from wire ropes so that no one side receives different exposure conditions from the other. The length of their suspending chain does not permit them to strike the sides of beams supporting the racks. The panels are insulated from their supports by means of rubber gaskets.

20. The racks at Guantanamo Bay are placed off shore sufficiently to insure that the panels remain submerged even at low tide. The panels are so situated in the racks that one side always faces seaward with the other side facing directly toward the shore. This does not permit a swaying of the panel and there is invariably a difference between the two faces of the panels exposed at this station.

21. At San Juan an entire series of panels is fastened to a large metal frame which is submerged in a horizontal position beneath the surface. Here too the panels are rigidly fixed and there is always a wide difference between the top and bottom sides. Of special interest is the fact that specimens exposed at San Juan foul much more rapidly than duplicate panels at Miami and Guantanamo.

22. In recording and reporting the changes occurring on the surface of these paint films, the service at Miami employs a standard form in which the extent of the change in amount of marine growth in indicated. So far the Air Stations have made photographs of the panels which have been submitted along with a report consisting of an extremely brief comment as to the condition of the films and panels themselves. The photographs are extremely valuable in judging the nature and extent of the fouling. However, this method of reporting does miss some of the smaller details which are of considerable importance, such as checking in the film and mild corrosion of the panel. It is to be hoped that soon a standard form for reporting these results may be submitted to the Bureau of Aeronautics and the Air Stations concerned for their approval.

23. Abrasion Resistance. For determining the abrasion resistance of the experimental formulations, an abrasion meter of a type described by Martin(1) is used. This apparatus was recently described in detail in Naval Research Laboratory Report P-1740 on "A Study of Organic Coatings for the Camouflage of Fleet Aircraft," dated 22 May 1941. Films of experimental materials are prepared on 4" x 4" aluminum alloy panels and the amount of

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(1) Abrasion Test - Martin, "Lacquer in Synthetic Enamel Finishes," p. 263, D. Van Nostrand Company.

abrasive is measured required to abrade through the film to the metal when the abrasive is allowed to strike the surface of a coated panel at an angle of 45° and under a carefully controlled pressure. The thickness of the film is measured with a micrometer and the specific abrasion resistance is reported in grams per mil as the ratio of the weight of abrasive to the thickness of the film. A minimum of four measurements is made on each panel, all of which must check within designated limits.

24. Wet Abrasion Resistance. The abrasion resistance of the same materials after the film has been soaked in water for 24 hours is measured in a similar manner. The panels containing the films are placed in a pan of distilled water where they are allowed to remain for 24 hours. Upon removal, adhering water is rapidly absorbed with blotting paper and the painted surfaces are further dried by means of a blast of compressed air. The abrasion resistance is then determined immediately before the film has had an opportunity to give up any appreciable amount of absorbed water.

25. Weathering. To determine the outdoor durability of the materials under investigation, panels are prepared for outdoor exposure at an angle of 45° facing south, which is generally accepted as the most reliable measure of their durable qualities. A minimum exposure time of 2 months during the summer and of 4 months during the winter is required to tentatively establish the quality of any product. At the conclusion of these exposure tests, a record is made of various qualities of the film such as loss of gloss, color retention, adhesion, chalking, checking, and general condition and appearance of the film.

26. Permeability. No quantitative measurements have been made to determine the actual rate at which water in the liquid phase permeates the pigmented films. However, an experiment was devised to determine the extent to which the ingredients of the paint film are leached out, or rather to determine their availability to their surrounding liquid medium. Panels of anodized aluminum alloy, size 1-1/2 x 6", are finished with the usual system identical with that for the larger exposure panels. These panels are placed on a specially devised apparatus which automatically lowers them into a solution of artificial sea water where they remain for 5 minutes. Next the panels are removed from the water and allowed to dry in the air for 10 minutes before being returned to the water again to repeat the cycle. The apparatus used to accomplish this cycle is described in detail in Naval Research Laboratory Report #P-1680 on "A Preliminary Study of Resins and Poisons to Determine Their Applicability to Anti-Fouling Compositions," dated 6 January 1941. After approximately two months, this operation has continued to the point where the paint film has begun to show some indication of deterioration and much of the ingredient material in the film has passed into solution. The composition of the original sea water is known as it was prepared synthetically by the Navy standard formula for sea water from A.C.S. analytical grade chemicals. The solutions are analyzed for chromate, mercury and copper ion and for any other ion added in the form of a salt to the original formulation. The chromate is calculated to zinc yellow and the metallic salts are reported as oxides. The relative amounts of these salts found in solution are a measure of the relative permeability of the various films.

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Appendix A

The detailed data accumulated and compiled concerning Series A, formulations numbers 1 through 20, are included herein. In the following list of formulae the formulation numbers are the same as those designated throughout the tables and text of this report. In some instances, the source of proprietary products is given. Table 1 lists the detailed exposure data as obtained from Miami, Guantanamo Bay and San Juan. Plates 1 through 20 are photographs of the test panels after six months' exposure at Miami. Figure 1 of each plate represents the panel as it appeared on its return, and Figure 2 shows the panel after loosely adhering mud and moss have been washed off with water and a medium stiff brush.

Series A - First exposed at Miami 27 November 1940. Removed from exposure racks at Miami 27 May 1941.

Formulation #1

Submitted by the Arco Company and described by them as "Arco #2 Anti-Fouling Paint."

Formulation #2

A proprietary product procured on the retail market known as "Mur-Cop" and manufactured by Westcott, Slade and Balcom.

Formulation #3

Submitted by the Pratt & Lambart Company and known as "Pratt & Lambart Anti-Fouling Paint."

Formulation #4

Submitted by the CopperCote Company, Incorporated, of New York and known as "CopperCote Anti-Fouling Paint #92B."

Formulation #5

Submitted by the Glidden Company of Reading, Pennsylvania, and designated as "Anti-Fouling Composition #11913."

Formulation #6

21.0 oz.	Insl-X Resin A (33-1/3% solids)
2.0 oz.	Super-Beckacite 3000.
11.88 oz.	Cuprous Oxide
7.5 oz.	Titanium Oxide
0.31 oz.	Carbon Black
22.0 oz.	Solvesso #1
2.0 oz.	Toluol

Solids - 51.7%
Weight/gal. - 11.3 pounds
Viscosity - 16.38 poises

27. Adhesion. Quantitative methods for the measurement of adhesion are entirely lacking. A qualitative test for establishing the relative adhesive qualities of protective coatings consists simply of scraping the coating from the metal surface by means of a knife, fingernail or some other hard object. The relative ease with which several coatings may be removed is the only semi-reliable measure of their adhesion. The adherence of the best films is recorded as excellent and then in descending quality they are rated as very good, good, fair, poor, and unsatisfactory. Aircraft coatings should rate good or better because of the tremendous drag occurring on hull bottoms during take-off or landing operations. When testing films of the kind studied herein, care should be exercised to rate adherence of the top coats to the primer as well as the adhesion of the entire system to the metal beneath.

28. Gloss. In the description of the various experimental coatings studied in this report, the degree of gloss has a double significance. Under present conditions all Fleet aircraft are finished with non-specular organic coatings and no finish devised for a hull bottom should exceed the limit of gloss specified for this type of product. Secondly, the decrease in gloss of an exposed panel is a direct measure of the weathering characteristics of the film. The poor quality films become dull and chalk the most rapidly. For measuring gloss as described in these experiments, a Gardner 60° glossmeter was used.

29. Color. No attempt has been made to hold the shade of these experimental compositions to that of the standard Navy non-specular lacquer M-485a. In no case, however, do these experimental materials contain pigments or compounds which would prevent tinting to a shade somewhat near that of the specified color. Any materials submitted for actual service tests on planes can be so tinted.

DATA OBTAINED

30. Submarine Exposure. The most significant data concerning these formulations are those showing their resistance or tendency to foul by marine organisms. These data are presented in complete detail in Table 1 of Appendices A, B and C for the three series of panels A, B and C. These tables list the coatings under test along with their composition or source (as in the case of proprietary products) and give the degree of fouling at the end of each month at the three exposure stations. Plates 1 through 20, Appendix A; 21 through 40, Appendix B; 41 through 60, Appendix C, show photographs of these panels after six months' exposure in Florida. Figure 1 of each plate is a photograph of the panel just as it was returned from the exposure station, and Figure 2 is a picture of the same panel after it has been scrubbed with water and a stiff brush to remove all of the loosely adhering material, such as mud and moss. The more strongly adhering barnacles and tubeworms are more clearly in evidence in Figure 2.

31. Formulae. The formulation for each individual coating along with pertinent physical data is included in Appendices A, B and C for each of the series A, B and C.

Formulation #11

See Formulation #21.

Formulation #12

6.0 oz. Insl-X Resin A (solid)
2.25 oz. Mercuric Oxide
4.88 oz. Cuprous Oxide
4.50 oz. Titanium Dioxide
0.187 oz. Carbon Black
12.00 oz. Toluol
7.4 oz. Solvesso #1

Solids: 47.7%
Wt/gal.: 10.6 pounds
Viscosity: 1.4 poises

Formulation #13

5.4 oz. Acryloid B-72 (solid)
0.6 oz. 1/2 Second N.C. (dry)
7.12 oz. Cuprous Oxide
4.5 oz. Zinc Oxide
0.187 oz. Carbon Black
0.257 oz. Ethyl Alcohol
4.65 oz. Ethyl Acetate
6.793 oz. Butyl Acetate
1.86 oz. Butyl Alcohol
11.32 oz. Toluol
3.72 oz. Aromatic Petroleum Naphtha, Type 1
3.5 oz. Cellosolve Acetate

Solids: 35.3%
Wt/gal.: 9.4 pounds
Viscosity: 15.1 poises

Formulation #14

5.4 oz. Acryloid B-72 (solid)
0.6 oz. 1/2 Sec. N.C. (dry)
6.0 oz. Zinc Cyanide
4.5 oz. Titanium Dioxide
0.187 oz. Carbon Black
0.257 oz. Ethyl Alcohol
2.425 oz. Ethyl Acetate
4.568 oz. Butyl Acetate
0.97 oz. Butyl Alcohol
10.04 oz. Toluol
1.94 oz. Aromatic Petroleum Naphtha, Type 1
3.5 oz. Cellosolve Acetate

Solids: 41.3%
Wt/gal.: 9.3 lbs.
Viscosity: 3.82 poises

32. Poison Effectiveness. The relative effectiveness of the various poisons studied is shown in Tables 1 through 4 for several different vehicle combinations. Table 1 indicates the value of several poisons and poison combinations when incorporated into a chlorinated rubber vehicle modified with pure phenolic resin. Table 2 gives similar figures for a pure chlorinated rubber vehicle; Table 3 represents the same relationship for methacrylate resin modified with nitrocellulose; while in Table 4 the resin combination consists of methacrylate resin modified with chlorinated rubber.

Table 1

Relative Effectiveness of Toxicants in
Chlorinated Rubber - Phenolic Resin

Formulation Number	Fouling Repellent	Barnacles						Moss					
		Month Exposure						Month Exposure					
		1	2	3	4	5	6	1	2	3	4	5	6
6	Cu_2O	x	x	x	x	x	xx	-	x	xxx	xxx	xxx	xxx
8	Cu_2O, $ZnCrO_4$	x	x	x	x	Gone	xxx	-	-	xx	xxx	xxx	xxx
17	Cu_2O, HgO	x Sm	xx	xx	x	x	xx	-	x	xx	xxx	xxx	xxx
18	$Zn(CN)_2$	x Sm	xx	xxx	xxx	xxx	xxxx	-	x	xx	xxx	xxx	xxx
11	Mare Island	-	-	x	x	-	-	-	-	x	x	x	x

Table 2

Relative Effectiveness of Toxicants in
Chlorinated Rubber

Formulation Number	Fouling Repellent	Barnacles						Moss					
		Month Exposure						Month Exposure					
		1	2	3	4	5	6	1	2	3	4	5	6
9	Cu_2O	x	x	x	x	Gone	xxx	-	-	x	x	x	xx
10	$Zn(CN)_2$	x	xx	xxx	xxx	x	xxx	-	-	x	xx	xx	x
12	HgO, Cu_2O	x	x	x	x	x	xxx	-	x	x	xx	xx	x
52	ZnN_2C	x	x	-	x	xxx	xxx	-	x	xx	xxx	xx	xx
53	$HgCl_2$	-	-	-	-	xx	xxx	-	x	xx	xx	xx	xx
54	Hg_2Cl_2	x	-	-	-	x	xx	-	x	xx	xx	x	x
11	Mare Island	-	-	x	x	-	-	-	-	x	x	x	x
82	Hg_2Cl_2	-	-	-	x	xx	xx	-	-	x	x	xx	xx
87	Hg_2Cl_2 Cu Resinate	-	-	-	-	-	-	-	-	-	-	-	x

Table 3

Relative Effectiveness of Toxicants in Methacrylate Resin - Nitrocellulose

Formulation Number	Fouling Repellent	Barnacles Month Exposure 1	2	3	4	5	6	Moss Month Exposure 1	2	3	4	5	6
7	Cu_2O, HgO	x Sm	x	x	x	x	xx	-	x	xx	xxx	xxx	xxx
13	Cu_2O	x	x	x	x	x	x	-	x	xxx	xxx	xxx	xx
14	$Zn(CN)_2$	x	xxx	xxx	xxx	xxx	xxx	-	x	xx	xxx	xxx	xxx
15	Cu_2O, $ZnCrO_4$	x	x	x	xx	x	xx	-	x	x	xx	xx	xx
55	ZnN_2C	x	x	x	xx	xx	xx	-	x	xx	xxx	xx	xx
57	Hg_2Cl_2	-	-	-	-	-	x	-	x	x	xx	x	x
11	Mare Island	-	-	x	x	-	-	-	-	x	x	x	x

Table 4

Relative Effectiveness of Toxicants in Methacrylate Resin - Chlorinated Rubber

Formulation Number	Fouling Repellent	Barnacles Month Exposure 1	2	3	4	5	6	Moss Month Exposure 1	2	3	4	5	6
16	Cu_2O	x	xx	xx	x	xx	xx	-	x	xxx	xxx	xxxx	xxx
19	Cu_2O	x	xx	x	x	x	x	-	x	xxx	xxx	xxxx	xxx
20	$Zn(CN)_2$	x	xx	xxx	xxx	xxx	xxx	-	x	xx	xx	xxx	xxx
56	$Zn(CN)_2$	x	x	x	x	xxx	xxx	-	-	x	xx	xx	x
58	Cu_2O	x	x	x	x	x	x	-	xxx	xxxx	xxxx	xxxx	xx
59	Cu_2O, HgO	x	x	-	-	-	x	-	x	xxx	xxx	xxx	xx
60	ZnN_2C	x	x	x	-	-	xx	-	x	xx	xxx	xx	x
11	Mare Island	-	-	x	x	-	-	-	-	x	x	x	x
83	Cu_2O, Cu Resinate	x	x	x	xxx	xxxx	xxxx	-	x	x	x	xx	xx
84	$HgCl_2$	-	-	xx	xxx	xxxx	xxxx	-	x	x	xx	xxx	xxx
85	Hg_2Cl_2	-	-	-	-	x	x	-	-	-	x	xxxx-x	xx
88	Cu_2O	-	-	x	x	x	x	-	xx	xxx	xxx	xx	xx

In these several tables the extent of barnacle or moss formation is indicated by the number of x's under each month of exposure. The key is as follows:

No change - Blank
Very slight - x
Definite - xx
Medium - xxx
Bad - xxxx
Very bad - xxxx-x

A panel covered with Mare Island hot plastic paint is included in each group as a control or reference.

33. Abrasion Resistance. The abrasion resistance of each of the materials was measured. The films were soaked in water for 24 hours, dried with blotting paper and a blast of compressed air, and the abrasion resistance measured immediately. Results of all of these measurements are correlated in Table 2 of Appendices A, B and C for each series reported herein.

34. Weathering. The outdoor durability characteristics of each film are reported in detail in Table 3 of Appendices A, B and C. The formulation numbers are the same as in all preceding tables and refer to the formula given under that number in each appendix. In each instance the initial, intermediate, and final gloss of the paint is given. This often serves as an index to the paint's durability. Furthermore, the paint's properties of color retention, adhesion, chalking and checking are listed.

35. Permeability. No actual permeability data are available at this writing on the rate at which water permeates the various films. Instead the composition of the extractants was determined in order to establish the rate or the extent to which certain significant constituents of the paint films dissolve or leach into the surrounding medium. Since all the systems studied were applied over zinc yellow primer, the chromate ion was common to each. In a few instances, some zinc yellow pigment was incorporated into the anti-fouling coating itself, thus making available a larger amount of chromate. As would be expected, solutions surrounding panels which contained some zinc yellow in the anti-fouling film were found to possess much larger percentages of chromate ion. This experiment was originally designed to test the corrosive qualities of the films, but since such significant amounts of inclosed salts did pass into solution, these solutions were examined for their mineral content. Unfortunately, no temperature control was applied and the data so obtained clearly indicate that temperature control is essential for interpretable results. For future experiments, panels will be submerged in distilled water under thermostatically controlled conditions. The solution tendencies of the film ingredients are listed in Table 4 of Appendices A, B and C.

36. Corrosion. To observe the condition of the anodized aluminum metal beneath the films described in the experiment in the preceding paragraph, the paint film on each panel was stripped off and the metal examined under a wide field microscope for any signs of corrosive action. The condition of the metal in each case is described in Table 4 of Appendices A, B and C.

CONCLUSIONS AND RECOMMENDATIONS

(a) Facts Established

37. In the light of exposures made to date, a measure of the relative intensity of fouling at the three exposure stations indicates that fouling and corrosive media occur to a much larger extent at San Juan than at Guantanamo Bay, while the conditions at Miami are somewhat in between. For this reason, the photographic record of exposures included in the appendices to this report is that made at Miami, since this represents the average of the three. Furthermore, it should be pointed out that considerable

difference in the type of growth exists between the three stations. Barnacles and small Hydroids covered with their calcareous tubes abound at Miami, and since these two growths adhere most tenaciously to any surface to which they become attached, they should be considered among the most objectionable. The barnacle growth at Guantanamo Bay is almost negligible by way of comparison, but large tube worms and some clams and oysters, along with considerable scum, predominate there. At San Juan the growth of barnacles, tube worms and Hydroids and Bryozoa is most abundant. Panels exposed there are fouled after two months to about the same degree as similar panels exposed at Guantanamo Bay for six months, or at Miami for four months. The relative value of anti-fouling coatings seems to be the same at all stations, thus providing good agreement between triplicate panels finished with identical coatings.

38. Proprietary Products. Special attention is directed to Plates 1, 3-5, 11 and 51 of the appendices. Plate 11 represents the condition of the Navy standard hot plastic coating after six months' exposure off the Florida coast. The other plates indicate the condition of five proprietary anti-fouling paints that were submitted to this Laboratory as the result of a circular letter from the Bureau of Aeronautics directed to eighteen leading manufacturers of paint products, inviting them to submit their recommendations and samples of their products adaptable to the solution of the problem at hand. The majority of them did not compare favorably with L12 lacquer, containing no poisons, as evinced by Plate 40 of Appendix B. This panel was covered with two coats of L12 white lacquer. Thus it may be concluded that the paint industry at large has no single coating to offer which it feels justified in recommending for the unqualified protection of aircraft hull bottoms from fouling encrustations.

39. Effectiveness of Various Poisons. As stressed earlier in this report, the extent of the formation of marine growth on any submerged painted surface is the function of two factors; namely, the effective toxicity to marine organisms of the poisonous compounds incorporated into the paint film, and the porosity of the film-forming material itself which makes available the desirable effects of these poisons. In Tables 1 through 4, the effectiveness of several toxicants is compared when used in several vehicles. One of the most striking points revealed by this classification is the fact that zinc cyanide seems to accelerate rather than retard the rate of fouling. This may possibly be explained by the assumption that the salt is hydrolyzed and the cyanide ion is broken down to a form in which the nitrogen becomes available to the organisms which would feed on it. This excessive growth occurs on all films in which zinc cyanide was used, regardless of the type of vehicle into which it was ground. In the two instances where zinc cyanamide was used, the rate of growth appears to be a little above normal but not quite so vigorous as in the case of the cyanide.

40. Again referring to Tables 1 through 4, it is evident that a chlorinated rubber vehicle is somewhat more inhibitive to marine growth than the other resins listed. With the exception of Formulation #10 containing zinc cyanide, each toxic combination appears to be somewhat more effective both against barnacles and moss than in any of the other vehicle formulations. In the face of these facts, it appears logical that chlorinated rubber con-

stitutes a more favorable film-forming substance for anti-fouling compositions.

41. These data further indicate that certain mercury salts, particularly mercurous chloride, possess a decided advantage over salts of copper for the prevention of fouling. Also the chlorides appear more effective than the oxides for both copper and mercury. However, mercuric chloride is much too soluble to be of value for any length of time, and in every instance a film containing it loses its effectiveness after three months and considerable encrustation of both barnacles and moss ensues.

42. From the three series of panels exposed and evaluated herein, the combination obtained in Formulation #87 in Table 2 is without question the most efficient yet obtained for prohibition of fouling. Consisting of two parts mercurous chloride to one part copper resinate dispersed in chlorinated rubber, a film is produced which for periods up to six months possesses a surface even cleaner than the Mare Island hot plastic which was applied as a control. The addition of copper resinate is shown to be quite necessary by comparison with Formulation #82, which is precisely the same formula except that the copper resinate has been omitted.

(b) Conclusions

43. From the foregoing results obtained with the few anti-fouling compositions submitted to this Laboratory for evaluation at the invitation of the Bureau of Aeronautics, it may be concluded that no commercial product is available which satisfactorily meets the demands of the problem at hand. From commercial products currently available, an untreated lacquer such as L12 will serve as satisfactorily as any so-called anti-fouling paint available in the industry. However, commercial production of Formulation #87 mentioned above (paragraph 42) should offer no difficulties.

44. From experimental materials examined herein, two conditions appear to have become well established which must be met in any formulation effecting a worthwhile retardation of marine growth on painted submerged surfaces. The first of these is the fact that only a formulation containing a mercury salt whose solubility is of the same order as that of mercurous chloride and a copper compound whose availability in the coating is of the same order as that of copper resinate will effectively prohibit fouling. The second fact that has established itself is that these salts must be in a paint vehicle of optimum permeability in order that the active salts themselves may be rendered most effective in repelling this growth. From the sum of the evidence so far presented, there is not a single composition adaptable to aircraft hulls and containing no mercurous chloride or similar mercury salt which possesses any value as an anti-fouling coating superior to that of an ordinary lacquer or Silosyn such as has been used in the past for finishing aircraft hull bottoms. Furthermore, it is demonstrated that copper salts alone are quite ineffective in a hard film, but when used in conjunction with a salt of mercury, the highest degree of protection is obtained.

45. This view is substantiated by all of the experimental evidence so far obtained in this study and no controversial facts have been uncovered either by experiment or in the literature for this type of coating. One or two investigators have claimed that copper alone is effective when used in soft plastic coatings which slowly erode away while a ship is in service, but this type of coating is impractical for use on aircraft. Consequently all the coatings so far formulated, either in this Laboratory or elsewhere, which warrant any consideration whatsoever, contain copper and mercury. The most effective form of these metals is found in mercurous chloride and copper resinate. These salts by themselves have been used to prevent fouling, and they have been demonstrated as quite effective.

(c) Recommendations

46. It is recommended that these studies be continued and expanded in order to evaluate other vehicles and poison combinations which show promise of improving upon the best formulation so far described. It is recognized that the best anti-fouling paint described herein does not possess the general durable characteristics of an orthodox film, and further efforts should be made to improve these qualities without impairing its excellent anti-fouling property.

47. It is further recommended that outside commercial laboratories be encouraged to continue their cooperation with the Naval Research Laboratory on the solution of this problem, and that their experimental formulations be checked here.

48. As exceptional coatings become available from time to time as a result of these investigations, it is recommended that provision be made for submitting them to exhaustive tests in service.

SUMMARY

49. This report describes the preparation and evaluation of approximately seventy experimental anti-fouling paints. In addition, the recommendations of five paint manufacturers have been tested, the results of which are reported. Of experimental coatings evaluated, twelve were submitted by outside laboratories cooperating on this problem, while the remainder were prepared here.

50. Concerning these formulations, complete data are given as to their anti-fouling qualities when exposed for periods up to six months at Miami, Guantanamo Bay and San Juan. Other physical properties common to all protective coatings also have been included.

51. A single coating has emerged as superior to all the others, and it is recommended for service test.

The detailed data accumulated and compiled concerning Series A, formulations numbers 1 through 20, are included herein. In the following list of formulae the formulation numbers are the same as those designated throughout the tables and text of this report. In some instances, the source of proprietary products is given. Table 1 lists the detailed exposure data as obtained from Miami, Guantanamo Bay and San Juan. Plates 1 through 20 are photographs of the test panels after six months' exposure at Miami. Figure 1 of each plate represents the panel as it appeared on its return, and Figure 2 shows the panel after loosely adhering mud and moss have been washed off with water and a medium stiff brush.

Series A - First exposed at Miami 27 November 1940. Removed from exposure racks at Miami 27 May 1941.

Formulation #1

Submitted by the Arco Company and described by them as "Arco #2 Anti-Fouling Paint."

Formulation #2

A proprietary product procured on the retail market known as "Mur-Cop" and manufactured by Westcott, Slade and Balcom.

Formulation #3

Submitted by the Pratt & Lambart Company and known as "Pratt & Lambart Anti-Fouling Paint."

Formulation #4

Submitted by the CopperCote Company, Incorporated, of New York and known as "CopperCote Anti-Fouling Paint #92B."

Formulation #5

Submitted by the Glidden Company of Reading, Pennsylvania, and designated as "Anti-Fouling Composition #11913."

Formulation #6

21.0 oz. Insl-X Resin A (33-1/3% solids)
2.0 oz. Super-Beckacite 3000.
11.88 oz. Cuprous Oxide
7.5 oz. Titanium Oxide
0.31 oz. Carbon Black
22.0 oz. Solvesso #1
2.0 oz. Toluol

Solids - 51.7%
Weight/gal. - 11.3 pounds
Viscosity - 16.38 poises

5.4 oz. Acryloid B-72 (solid)
0.6 oz. 1/2 second N.C. (dry)
2.25 oz. Mercuric Oxide
4.88 oz. Cuprous Oxide
4.5 oz. Titanium Dioxide
0.175 oz. Carbon Black
0.257 oz. Ethyl Alcohol
3.75 oz. Ethyl Acetate
5.893 oz. Butyl Acetate
1.5 oz. Butyl Alcohol
11.10 oz. Toluol
3.0 oz. Aromatic Petroleum Naphtha, Type 1
3.5 Cellosolve Acetate

Solids: 39.5%
Viscosity: 3.965 poises
Wt/gal.: 9.5 pounds

Formulation #8

3.2 oz. Insl-X Resin A (solid)
0.8 oz. Super-Beckacite 3000 (solid)
4.0 oz. Cuprous Oxide
3.0 oz. Titanium Dioxide
0.25 oz. Carbon Black
0.75 oz. Zinc Yellow
6.00 oz. Toluol
12.00 oz. Solvesso #1

Solids: 45.5%
Wt/gal: 10.7 pounds
Viscosity: 0.95 poises

Formulation #9

6 oz. Insl-X Resin A (solid)
7.12 oz. Cu_2O
4.5 oz. Zinc Oxide
.187 oz. Carbon Black
12.0 oz. Toluol (from Insl-X Resin A)
8.0 oz. Solvesso #1

Solids: 47.1%
Wt/gal.: 10.8 pounds
Viscosity: 3.495 poises

Formulation #10

6 oz. Insl-X Resin A (solid)
6 oz. Zinc Cyanide
4.5 oz. Zinc Oxide
.187 oz. Carbon Black
12.0 oz. Toluol (from Insl-X Resin A)
10.4 oz. Solvesso #1

Solids: 42.7%
Wt/gal.: 9.3 pounds
Viscosity: 0.976 poises

Formulation #11

See Formulation #21.

Formulation #12

6.0 oz. Insl-X Resin A (solid)
2.25 oz. Mercuric Oxide
4.88 oz. Cuprous Oxide
4.50 oz. Titanium Dioxide
0.187 oz. Carbon Black
12.00 oz. Toluol
7.4 oz. Solvesso #1

Solids: 47.7%
Wt/gal.: 10.6 pounds
Viscosity: 1.4 poises

Formulation #13

5.4 oz. Acryloid B-72 (solid)
0.6 oz. 1/2 Second N.C. (dry)
7.12 oz. Cuprous Oxide
4.5 oz. Zinc Oxide
0.187 oz. Carbon Black
0.257 oz. Ethyl Alcohol
4.65 oz. Ethyl Acetate
6.793 oz. Butyl Acetate
1.86 oz. Butyl Alcohol
11.32 oz. Toluol
3.72 oz. Aromatic Petroleum Naphtha, Type 1
3.5 oz. Cellosolve Acetate

Solids: 35.3%
Wt/gal.: 9.4 pounds
Viscosity: 15.1 poises

Formulation #14

5.4 oz. Acryloid B-72 (solid)
0.6 oz. 1/2 Sec. N.C. (dry)
6.0 oz. Zinc Cyanide
4.5 oz. Titanium Dioxide
0.187 oz. Carbon Black
0.257 oz. Ethyl Alcohol
2.425 oz. Ethyl Acetate
4.568 oz. Butyl Acetate
0.97 oz. Butyl Alcohol
10.04 oz. Toluol
1.94 oz. Aromatic Petroleum Naphtha, Type 1
3.5 oz. Cellosolve Acetate

Solids: 41.3%
Wt/gal.: 9.3 lbs.
Viscosity: 3.82 poises

5.4 oz. Acryloid B-72 (solid)
0.6 oz. 1/2 Sec. N.C. (dry)
6.0 oz. Cuprous Oxide
4.5 oz. Zinc Oxide
0.187 oz. Carbon Black
1.5 oz. Zinc Yellow
0.257 oz. Ethyl Alcohol
3.175 oz. Ethyl Acetate
5.318 oz. Butyl Acetate
1.270 oz. Butyl Alcohol
10.64 oz. Toluol
2.54 oz. Aromatic Petroleum Naphtha, Type 1
3.5 oz. Cellosolve Acetate

Solids: 40.5%
Wt/gal.: 10.4 pounds
Viscosity: 12.55 poises

Formulation #16

5.4 oz. Acryloid B-75 (solid)
0.6 oz. 10 cps Chlorinated Rubber (solid)
7.12 oz. Cuprous Oxide
4.5 oz. Titanium Dioxide
0.187 oz. Carbon Black
6.8 oz. Cellosolve Acetate
0.9 oz. Butyl Acetate
9.5 oz. Solvesso #1
6.3 oz. Solvesso #3

Solids: 43.0%
Wt/gal.: 10.9 pounds
Viscosity: 2.615 poises

Formulation #17

6.4 oz. Insl-X Resin A (solid)
1.6 oz. Super-Beckacite #3000 (solid)
3.0 oz. Mercuric Oxide
6.5 oz. Cuprous Oxide
6.0 oz. Titanium Dioxide
0.25 oz. Carbon Black
12.00 oz. Toluol
11.70 oz. Solvesso #1

Solids: 50.1%
Wt./gal.: 11.7 pounds
Viscosity: 1.075 poises

6.4 oz. Insl-X Resin A (solid)
1.6 oz. Super-Beckacite #3000 (solid)
8.0 oz. Zinc Cyanide
6.0 oz. Titanium Dioxide
0.25 oz. Carbon Black
12.0 oz. Toluol (from Insl-X and Beckacite)
18.3 oz. Solvesso #1

Solids: 42.3%
Wt./gal.: 9.7 pounds
Viscosity: 0.956 poises

Formulation #19

4.8 oz. Insl-X Resin A (solid)
1.2 oz. Acryloid B-72 (solid)
7.12 oz. Cuprous Oxide
4.5 oz. Titanium Dioxide
0.5 oz. Carbon Black
9.0 oz. Toluol (from Insl-X and Acryloid)
10.2 oz. Solvesso #1

Solids: 47.1%
Wt./gal.: 10.9 pounds
Viscosity: 8.95 poises

Formulation #20

4.8 oz. Insl-X Resin A (solid)
1.2 oz. Acryloid B72 (solid)
6.0 oz. Zinc Cyanide
4.5 oz. Titanium Oxide
0.187 oz. Carbon Black
9.0 oz. Toluol (from Insl-X and Acryloid)
14.4 oz. Solvesso #1

Solids: 40.7%
Wt/gal.: 9.2 pounds
Viscosity: 3.372 poises

Formulation #21 or #11

Standard Mare Island Hot Plastic Paint which was used as the control product - Series A.

Formulations #22 to 40, inclusive, and #11 (corresponding to #21) were duplicates of Nos. 1 to 21, inclusive. These numbers were sent to Guantanamo and in all future formulations, the same numbers were applied to each formulation and sent to each of the three exposure stations.

	Paint													tered			
4			3	" "	—	—	x "	x	xxx	xx	—	"	"	On rivets	Heavy	"	"
			4	" "	x Segm	x Ph'd	x "	x	xxx	xx	—	"	"	" "	Very heavy	"	"
			5	" "	x "	x "	x	x	xxx	xxx	—	Heavy	Light at top	Few scattered	Heavy	Returned	Retur
			6	" "	x "	x "	xxx "	xx	xx	xxx	—	"	"	Scattered	"	"	"
5	Glidden Anti-Fouling Paint		1	Gd	—	—	x Small	x	—	x	—	Heavy	Heavy	Few started	Few started	Heavy	Light
			2	"	—	—	x "	x	x	xx	—	"	Scattered weeds	Few	Scattered	Very heavy	"
			3	"	—	—	x "	x	xxx	xx	x	"	Light at top	Few	Heavy	" "	"
			4	"	—	x Pinhd	x "	x	xxx	xx	x	"	" " "	Few	Very heavy	" "	Mediu
			5	"	—	x "	x	x	xxx	xxx	x	Heavy, spotty	" " "	Light scattered	Heavy	Returned	Retur
			6	"	—	x "	xxx	xx	xxx	xxx	xxxx	Medium spotty	" " "	Few	Very heavy	"	"
6	Chlorinated Rubber	Cu_2O	1	Gd	xxxx Rivets & Edges	—	x Small	—	—	x	—	Spotty, light	Very light	Few started	Few started	Heavy	Light
	Phenolic		2	"	xxxx " "	—	x "	—	x	xx	—	Medium	Light	Scattered small	Scattered	Very heavy	"
			3	"	xxxx " "	—	x "	x	xxx	xx	—	"	"	Scattered	"	" "	"
			4	"	xxxxx " "	—	x "	x	xxx	xxx	x	"	"	"	"	" "	Heavy
			5	"	xxxxx " "	—	x	x	xxx	xxxx	x	Very heavy	Heavy at top	Heavy	"	Returned	Retur
			6	"	xxxxx " "	—	xx	xx	xxx	xxxx	xx	Heavy	" " "	Scattered	"	"	"
7	Methacrylate	Cu_2O	1	Gd	xx Riv.& Ed.	—	x Small	—	—	x	—	Spotty, light	Very light	Few started	Few started	Heavy	Light
			2	"	xx " "	—	x "	—	x	xxx	—	Light	" "	Scattered small	Scattered	Very heavy	Mediu
	Nitro-cellulose	HgO	3	"	xx " "	x 1"dia.	x "	—	xx	x	—	"	Light	Few	Medium	" "	"
			4	"	xx " "	x "	x "	—	xxx	xxx	—	Medium	"	"	"	" "	Heavy
			5	"	xx " "	x "	x	—	xxx	xxxx	—	Heavy	Light at top	Some	Heavy	Returned	Retur
			6	"	xx " "	x "	xx	xxx	xxx	xxxx	—	"	Medium at top	Light	"	"	"
8	Chlorinated Rubber	Cu_2O	1	Gd	x Rivets	—	x Small	—	—	x	—	Light	Light	Few started	Few started	Heavy	Light
			2	"	x "	—	x "	—	x	xxx	—	Heavy	"	Scattered	Scattered	Very heavy	"
		Zn yellow	3	"	xx "	—	xx "	x	xx	x	—	"	"	On rivets	Heavy	" "	Mediu
	Phenolic		4	"	xxx "	—	xx "	x	xxx	xxx	—	"	"	" "	"	" "	"
			5	"	xxx	—	xx	x	xxx	xxxx	—	Very heavy	Heavy at top	Few scattered	Medium	Returned	Retur
			6	"	xxx	—	xxx	xx	xxx	xxxx	xx	Medium	Light at top	" "	Heavy	"	"
9	Chlorinated Rubber	Cu_2O	1	Gd	x Rivets	—	x Seed	—	—	x	—	Spotty, light	Light	Few started	Few started	Medium	Light
			2	"	x "	—	x Small	—	—	x	—	Very heavy	Medium	On rivets	Scattered at bottom	Heavy with one bare spot	Mediu
			3	"	x "	—	x "	—	x	x	—	Heavy	"	Scattered small	Scattered	Very heavy	"
			4	"	x "	—	x "	—	x	xx	—	Medium	"	" "	"	" "	Heavy
			5	"	x "	—	Gone	—	x	xxxx	—	Heavy	Medium at top	Few scattered	Medium	Returned	Retur
			6	"	x " & Seams	—	xxx	xx	xx	xxx	—	"	" " "	Few	Medium	"	"
10	Chlorinated Rubber	$Zn(CN)_2$	1	Gd	x Rivets	—	x Seed	—	—	—	—	Light	Light	Few started on rivets	Few started	Light	Very
			2	"	x "	—	xx Small	—	—	—	—	Medium	"	Scattered small	Heavy	Heavy	Light
			3	"	x "	—	xxx "	—	x	x	—	"	Light at top	Many small	"	"	"
			4	"	x "	—	xxx "	—	xx	xx	—	Heavy at top	" " "	" "	"	Very heavy	Mediu
			5	"	x "	—	x	—	xx	xxx	—	Medium at top	" " "	Scattered	Medium	Returned	Retur
			6	"	x "	—	xxx	x	x	xxxx	—	Light moss	" " "	"	"	"	"
11	Mare Island		1	xx Gra.	xx Riv.&Ed.	—	—	—	—	xxx	—	Very light at seam	Trace at seam	No barnacles	No barnacles	Light	None
			2	xx "	xx " "	—	—	—	—	xxx	—	Light spotty	Very light	" "	" "	Heavy on one side, other light	Very
			3	xx "	xx " "	—	x Small	—	x	xxx	—	" "	Very light spotty	On seam	On rivets	Light	"
			4	xx "	xx " "	—	x "	—	x	xxx	—	" "	Very light at top	" "	On seam & riv.	Heavy on one side	"
			5	xx "	xx " "	—	Gone	—	x	xxx	—	Light	Very light	" "	Started	Returned	Retur
			6	xx "	xx " "	—	"	—	x	xxx	—	"	Light	Rivets	Few	"	"

TABLE I

Anti-Fouling Properties of Experimental Films - Series A

				Miami Exposure								Quantanamo Exposure				San Juan Exp
												Vegetable Growth		Barnacles & Tube Worms		
Formulation Number	Resin Composition	Fouling Repellent	Months Exposed	Color	Corrosion	Blisters	Barnacles	Tube Worms	Moss	Scum	Oysters & Sponge	Front	Rear	Front	Rear	Vegetable Growth
1	Proprietary Product Arco #2		1	Gd	Gd	—	x Small	--	—	x	—	Heavy	Light	Few started	Few started	Medium
			2	"	"	xx Ph'd	x "	--	x	xx	—	Ex. heavy	Heavy	Scattered	Scattered	Very heavy
			3	"	"	xx "	x "	--	xxx	xxx	x (O)	" "	"	Removed	Numerous	" "
			4	"	"	xx "	x "	--	xxx	xxx	x (O)	" "	Medium	Few	Heavy	" "
			5	"	"	xx "	x	x	xxxx	xxx	x (O)	" "	"	Very few	Very heavy	--
			6	"	x	xx "	xxx	xx	xxxx	xxx	x(O)xx(S)	Little	—	Scattered	Heavy	--
2	Proprietary Product		1	Gd	xx Rivets	—	—	—	—	x	—	Very slight	None	Rivet Heads	Rivet Heads	None
			2	"	xx "	—	—	—	—	xx	—	Light	Moss at top	" "	" "	Medium
			3	"	xx "	—	—	—	x	xx	—	Spotty	Spotty	" "	Very few	Heavy
	Mur-Cop		4	"	xx "	—	—	—	x	xx	—	Light	"	" "	" "	Very heavy
			5	"	xx "	—	—	—	x	x	—	Spotty	Light	" "	Scattered	Returned
			6	"	xx "	—	x	x	x	xx	—	"	"	Started	"	"
3	Proprietary Product		1	Gd	x Rivets	None	x Small	x	—	x		Heavy	Medium	Few started	Few started	Heavy
			2	"	x "	"	xx "	x	x	xx	x (S)	"	Heavy	" "	Scattered	Extra heavy
			3	"	x "	"	xx "	x	x	xxx		"	"	None	"	" "
	Pratt & Lambert A-F Paint		4	"	x "	"	xx "	x	xxx	xxx		"	"	Scattered	Heavy	" "
			5	"	x "	"	xx "	x	xxxx		x (O)	"	"	"	"	Returned
			6	"	x "	"	xx "	xx	xxxx		xxxx (S) x (O)	Moss and weeds at top	Medium at top	"	Very heavy	" -
4	Copper Cote Anti-Fouling Paint		1	x DK	—	—	x Small	—	—	x	—	Light, spotty	Very light	Few started	Few started	Heavy
			2	" "	—	—	x "	—	x	x	—	Medium	Light	Small, scattered	Scattered	"
			3	" "	—	—	x "	x	xxx	xx	—	"	"	On rivets	Heavy	"
			4	" "	x Seam	x Ph'd	x "	x	xxx	xx	—	"	"	" "	Very heavy	"
			5	" "	x "	x "	x	x	xxx	xxx	—	Heavy	Light at top	Few scattered	Heavy	Returned
			6	" "	x "	x "	xxx "	xx	xx	xxx	—	"	"	Scattered	"	"
5	Glidden Anti-Fouling Paint		1	Gd	—	—	x Small	x	—	x	—	Heavy	Heavy	Few started	Few started	Heavy
			2	"	—	—	x "	x	x	xx	—	"	Scattered weeds	Few	Scattered	Very heavy
			3	"	—	—	x "	x	xxx	xx	x	"	Light at top	Few	Heavy	" "
			4	"	—	x Pinhd	x "	x	xxx	xx	x	"	" " "	Few	Very heavy	" "
			5	"	—	x "	x	x	xxx	xxx	x	Heavy, spotty	" " "	Light scattered	Heavy	Returned
			6	"	—	x "	xxx	xx	xxx	xxx	xxxx	Medium spotty	" " "	Few	Very heavy	"
6	Chlorinated Rubber	Cu_2O	1	Gd	xxxx Rivets & Edges	—	x Small	—	—	x	—	Spotty,light	Very light	Few started	Few started	Heavy
	Phenolic		2	"	xxxx " "	—	x "	—	x	xx	—	Medium	Light	Scattered small	Scattered	Very heavy
			3	"	xxxx " "	—	x "	x	xxx	xx	—	"	"	Scattered	"	" "
			4	"	xxxxx " "	—	x "	x	xxx	xxx	x	"	"	"	"	" "
			5	"	xxxxx " "	—	x	x	xxx	xxxx	x	Very heavy	Heavy at top	Heavy	"	Returned
			6	"	xxxxx " "	—	xx	xx	xxx	xxxx	xx	Heavy	" " "	Scattered	"	"
7	Methacrylate	Cu_2O	1	Gd	xx Riv.& Ed.	—	x Small	—	—	x	—	Spotty,light	Very light	Few started	Few started	Heavy
			2	"	xx " "	—	x "	—	x	xxx	—	Light	" "	Scattered small	Scattered	Very heavy
	Nitro-cellulose	HgO	3	"	xx " "	x 1"dia.	x "	—	xx	x	—	"	Light	Few	Medium	" "
			4	"	xx " "	x "	x "	—	xxx	xxx	—	Medium	"	"	"	" "
			5	"	xx " "	x "	x	—	xxx	xxxx	—	Heavy	Light at top	Some	Heavy	Returned
			6	"	xx " "	x "	xx	xxx	xxx	xxxx	—	"	Medium at top	Light	"	"
	Chlorinated Rubber	Cu_2O	1	Gd	x Rivets	—	x Small	—	—	x	—	Light	Light	Few started	Few started	Heavy
			2	"	x "	—	x "	—	x	xxx	—	Heavy	"	Scattered	Scattered	Very heavy
		Zn yellow	3	"	xx "	—	xx "	x	xx	x	—	"	"	On rivets	Heavy	" "

Table II

Abrasion Resistance of Anti-Fouling Coatings - Series A

	Dry Film			Wet Film - 24 hrs. Soak		
Formulation Number	Average Wt. of Abrasive	Film Thickness in Mils	Specific Abrasion Wt./Thickness	Average Wt. of Abrasive	Film Thickness in Mils	Specific Abrasion
1						
2						
3						
4	21.8	1.4	15.6	20.1	1.4	14.4
5	70.1	1.4	50.1	53.8	1.4	38.4
6	28.3	1.1	25.7	8.5	1.1	7.7
7	63.7	1.3	49.0	N.G.	1.3	N.G.
8	21.7	0.7	31.0	4.2	0.7	6.0
9	29.0	1.1	26.4	22.3	1.1	20.2
10	61.8	2.1	29.4	33.4	2.1	15.9
11	--	--	--	--	--	--
12	35.3	1.0	35.3	16.6	1.0	16.6
13	24.5	1.0	24.5	14.4	1.0	14.4
14	48.6	1.6	30.4	N.G.	1.6	N.G.
15	49.1	2.0	24.6	10.8	2.0	5.4
16	--	--	--	--	--	--
17	17.2	1.4	12.3	6.6	1.4	4.7
18	36.1	0.9	40.1	26.6	0.9	29.6
19	38.1	1.5	25.4	9.9	1.5	6.6
20	68.8	2.2	31.3	40.5	2.2	18.4

Abrasion Resistance of Anti-Fouling Coatings - Series A

Formulation Number	Dry Film			Wet Film - 24 hrs. Soak		
	Average Wt. of Abrasive	Film Thickness in Mils	Specific Abrasion Wt./Thickness	Average Wt. of Abrasive	Film Thickness in Mils	Specific Abrasion
1						
2						
3						
4	21.8	1.4	15.6	20.1	1.4	14.4
5	70.1	1.4	50.1	53.8	1.4	38.4
6	28.3	1.1	25.7	8.5	1.1	7.7
7	63.7	1.3	49.0	N.G.	1.3	N.G.
8	21.7	0.7	31.0	4.2	0.7	6.0
9	29.0	1.1	26.4	22.3	1.1	20.2
10	61.8	2.1	29.4	33.4	2.1	15.9
11	--	--	--	--	--	--
12	35.3	1.0	35.3	16.6	1.0	16.6
13	24.5	1.0	24.5	14.4	1.0	14.4
14	48.6	1.6	30.4	N.G.	1.6	N.G.
15	49.1	2.0	24.6	10.8	2.0	5.4
16	--	--	--	--	--	--
17	17.2	1.4	12.3	6.6	1.4	4.7
18	36.1	0.9	40.1	26.6	0.9	29.6
19	38.1	1.5	25.4	9.9	1.5	6.6
20	68.8	2.2	31.3	40.5	2.2	18.4

Table III

Weathering Characteristics of Anti-Fouling Paints - Series A

Formulation Number	Gloss In Mils Initial	Gloss In Mils 2 Mos.	Gloss In Mils 5 Mos.	Panel Condition After Five Months' Roof Exposure: Color Retention	Adhesion	Chalking	Checking
1	95	79	15	Fair. Darkened.	Excellent. No change.	None	None
2	87	7	7	Darkened. Dirty.	Good. No change.	"	"
3	35	36	9	Darkened considerably.	" " "	"	"
4	120	43	4	Darkened. Dirty.	" " "	"	"
5	75	45	14	Good. Slightly dirty.	" " "	"	"
6	19	7	5	Poor. Faded.	Very good. No change.	Very severe	"
7	15	4-1/2	3	" "	Fair. Too brittle.	" "	"
8	10	14	13	Faded slightly.	Very good. Slight change.	Very good	"
9	8	9	12	Fair. Darkened slightly.	Excellent. No change.	None	"
10	6	14	20	Medium fading.	" " "	"	"
11	None			Darkens.	Unsatisfactory.	"	Exceedingly bad.
12	20	27	13	Faded badly.	Excellent. Unchanged.	Very severe	None
13	2	6	2	Fair. Slight darkening.	Fair. Too brittle.	None	"
14	4	4	2	" " "	Poor. " "	Very severe	"
15	2-1/2	0	2	Good. " "	Fair. " "	None	"
16	10	5	3	Poor. Fades to gray.	Medium. " "	Very severe	"
17	20	10	5	" " " "	Excellent. No change.	" "	"
18	5	8	20	Good.	Medium. Too brittle.	Poor	Few blisters.
19	6	3	3	Poor. Fades to gray.	Poor.	Very severe	None
20	2	2	4	Very good.	Good.	" "	"

Table IV

Solution Tendencies of Paint Ingredients - Series A

Formulation Number	Ingredients	Solution Analysis				Condition of Aluminum after Removal of Paint Film
		pH	Mgs. of Zn Yellow	Mgs. of Cu_2O	Mgs. of HgO	
1		5.9	10.21			Unaffected.
2		6.15	0.89	0.41		Mildly etched.
3		6.15	38.08	0.41		Unaffected.
4		6.25	18.28	1.83		Small pits and corroded spots.
5		5.80	23.38	0.20		Extremely mild etching. Microscopic pits.
6	Cu_2O	6.25	12.88	1.22		Unaffected
7	HgO, Cu_2O	6.20	9.57	0.45	0.206	Slightly etched.
8	$ZnCrO_4$, Cu_2O	6.50	21.18	4.16		Unaffected.
9	Cu_2O	6.25	11.32	4.75		"
10	$Zn(CN)_2$	6.90	9.48			Microscopically etched.
11	Mare Island					
12	HgO, Cu_2O	6.45	19.97	3.60	0.20	Unaffected.
13	Cu_2O	6.25	10.08	2.47		"
14	$Zn(CN)_2$	6.85	8.92			Numerous corroded spots.
15	$ZnCrO_4$, Cu_2O	6.75	26.70	0.81		Unaffected.
16	Cu_2O	6.45	13.80	5.18		Very good. Two small spots.
17	HgO, Cu_2O	6.55	27.30	2.70	1.75	Unaffected.
18	$Zn(CN)_2$	6.95	16.85			"
19	Cu_2O	6.30	17.05	7.51		Strongly attacked. Corroded.
20	$Zn(CN)_2$	6.80	10.78			Unaffected.

FIG. 1

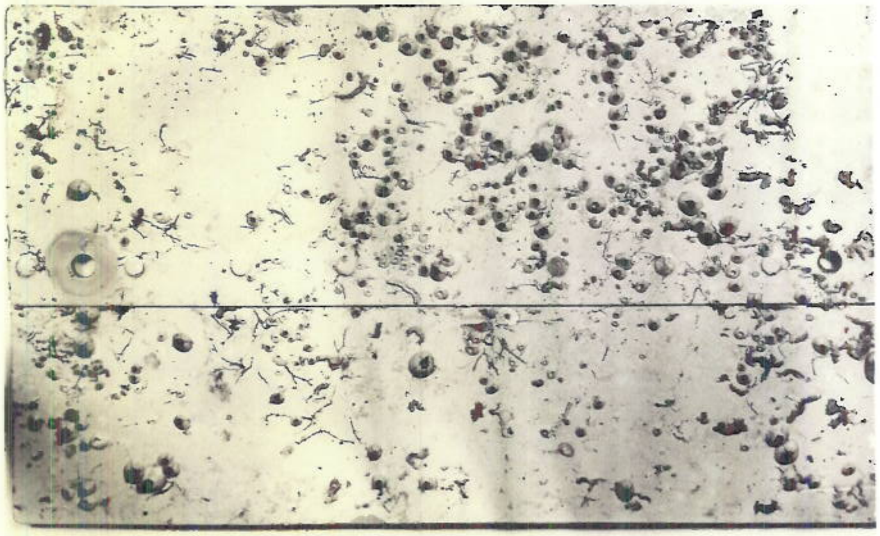

FIG. 2

PLATE I

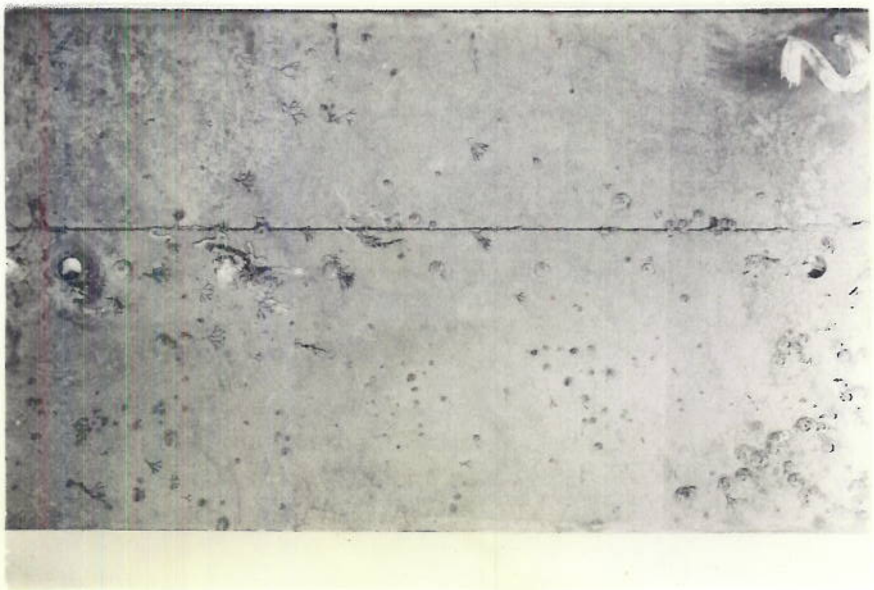

FIG. 1

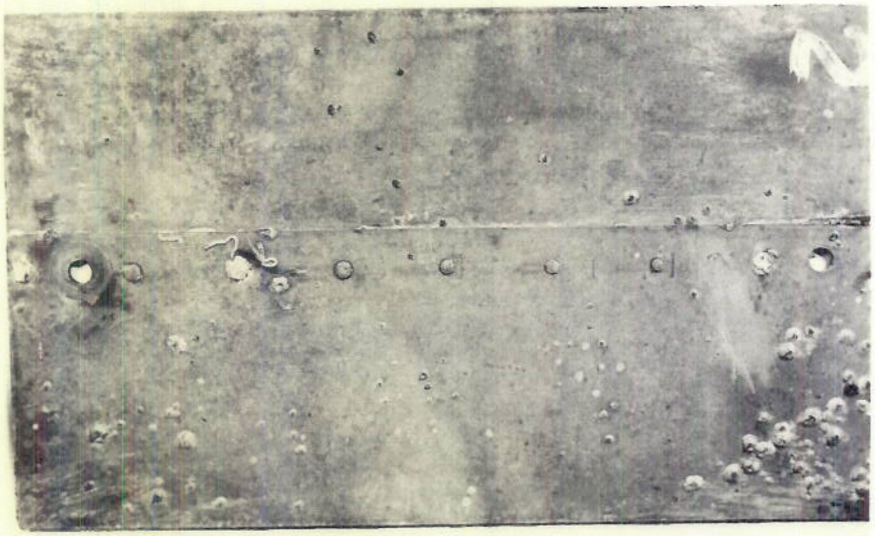

FIG. 2

PLATE 2

FIG. 1

FIG. 2

PLATE 3

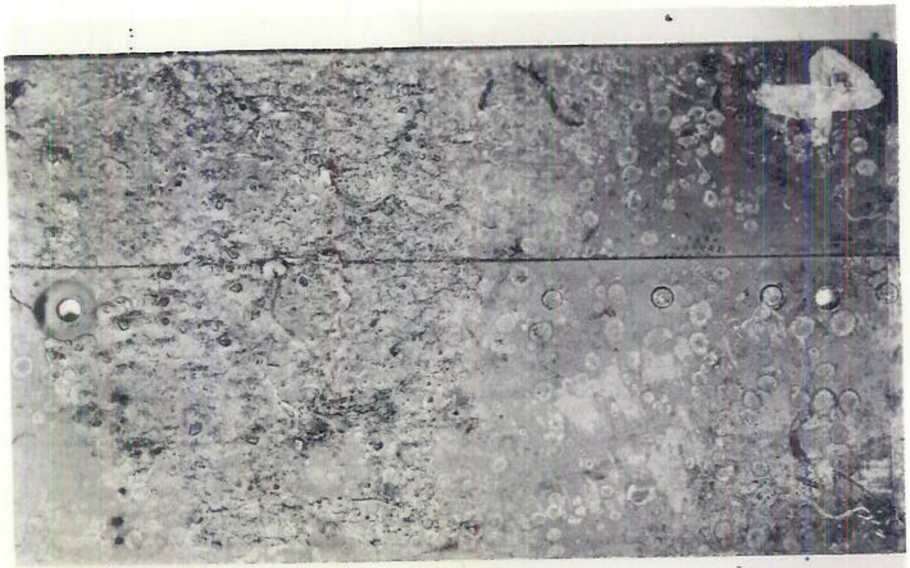

FIG. 1

FIG. 2

PLATE 4

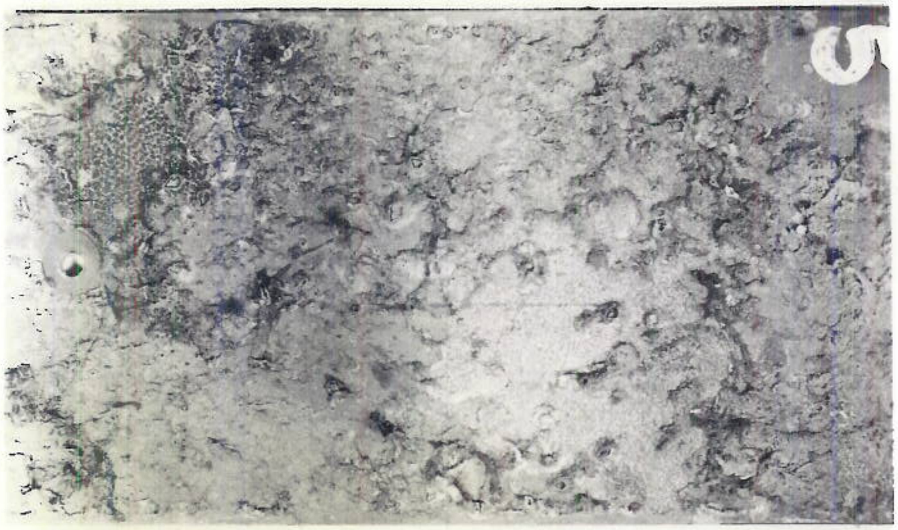

FIG. 1

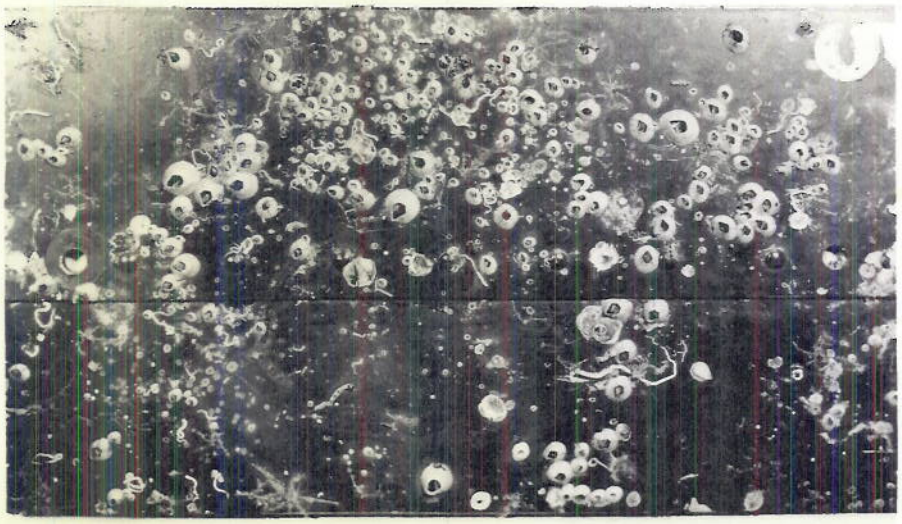

FIG. 2

PLATE 5

FIG. 1

FIG. 2

PLATE 6

FIG. 1

FIG. 2

PLATE 7

FIG. 1

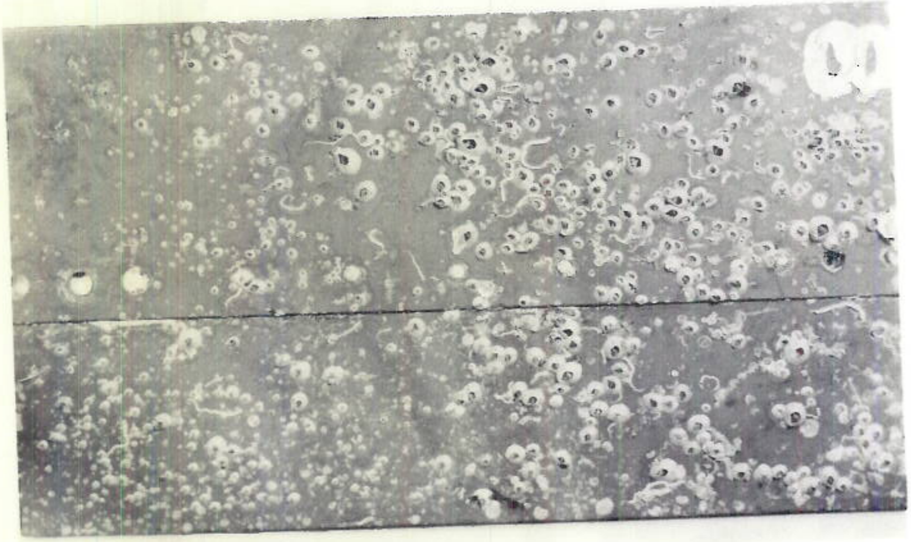

FIG. 2

PLATE 8

FIG. 1

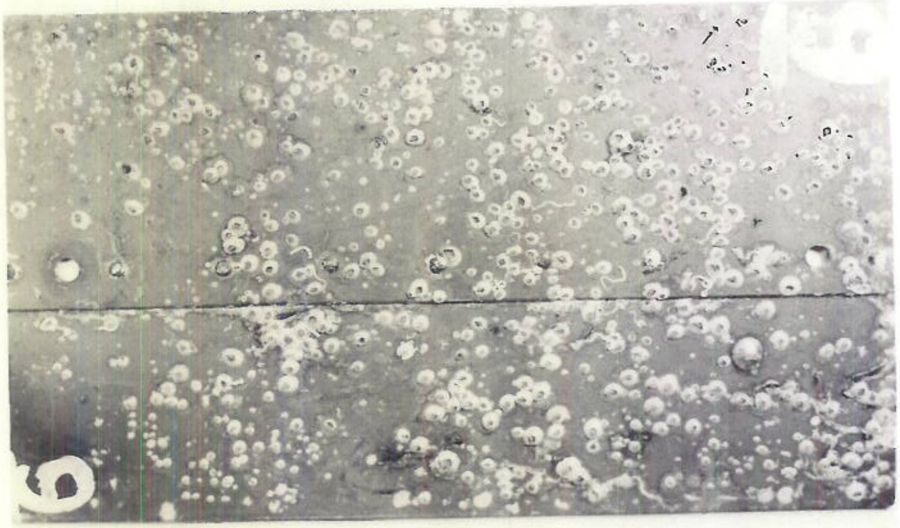

FIG. 2

PLATE 9

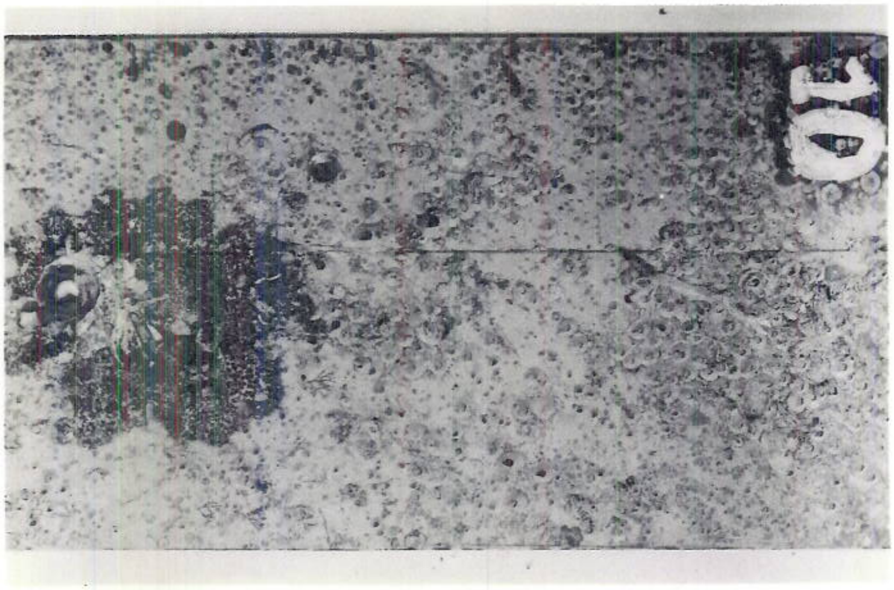

FIG. 1

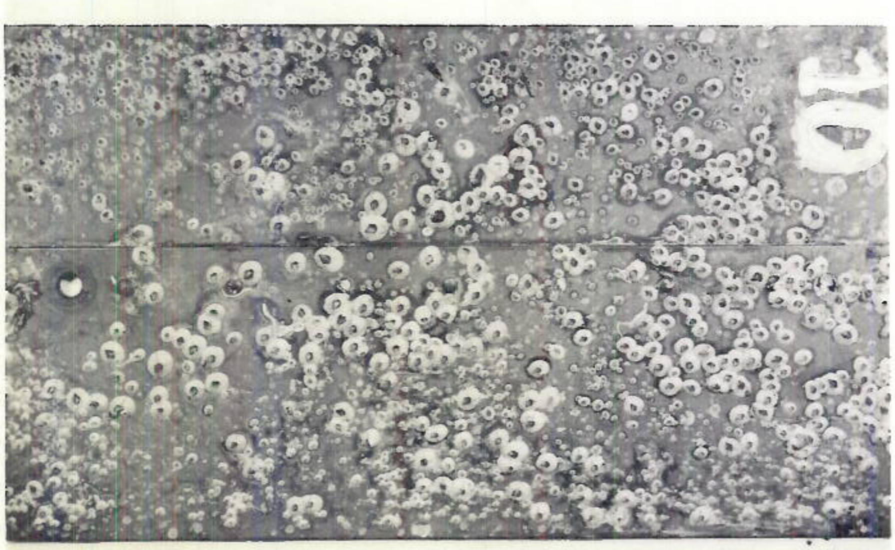

FIG. 2

PLATE 10

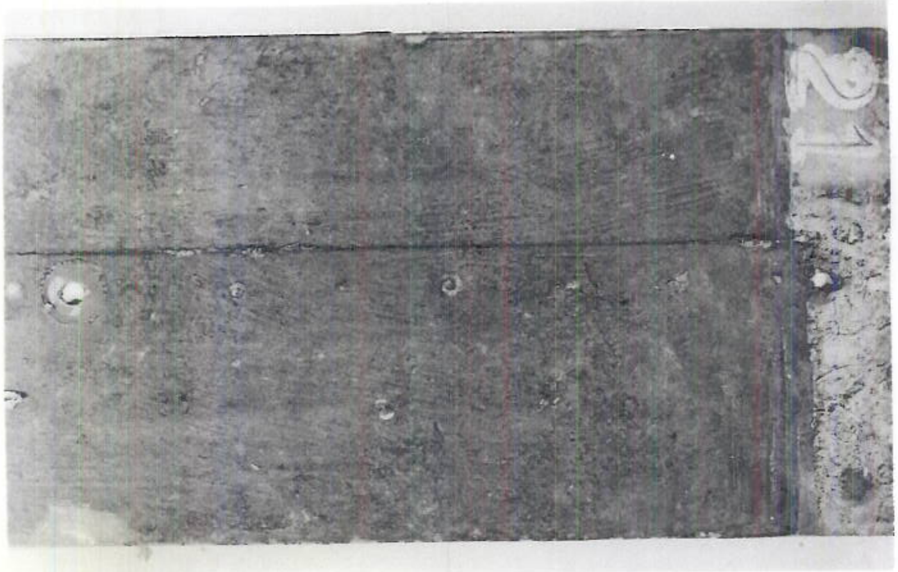

FIG. 1

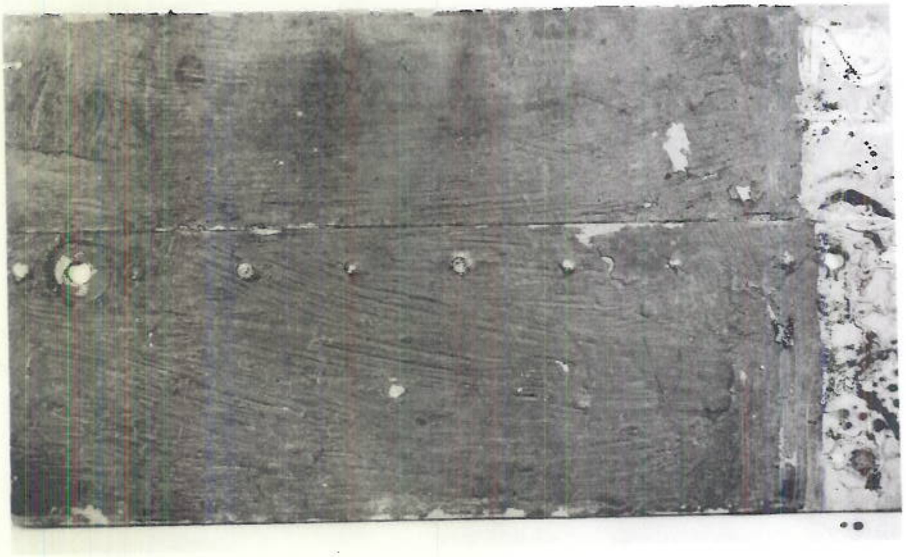

FIG. 2

PLATE II

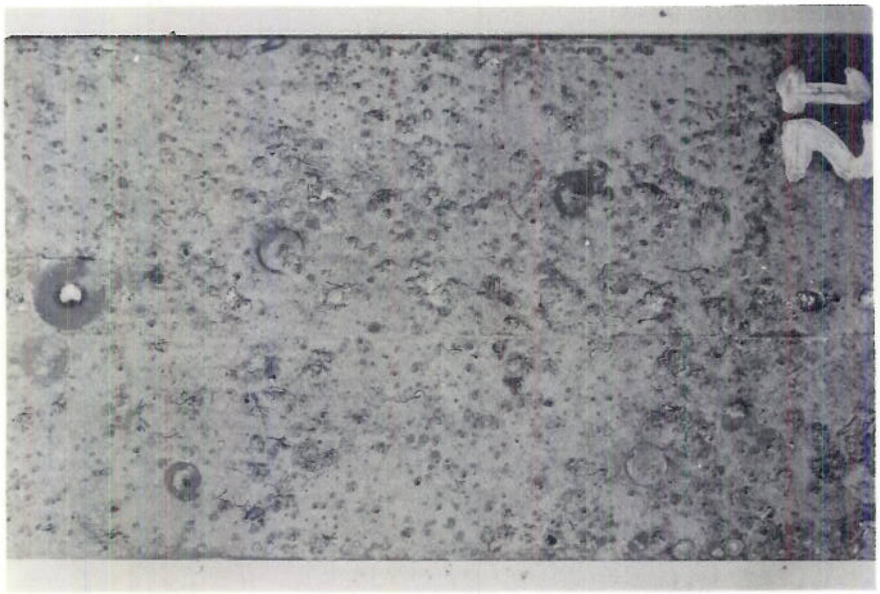

FIG. 1

FIG. 2

PLATE 12

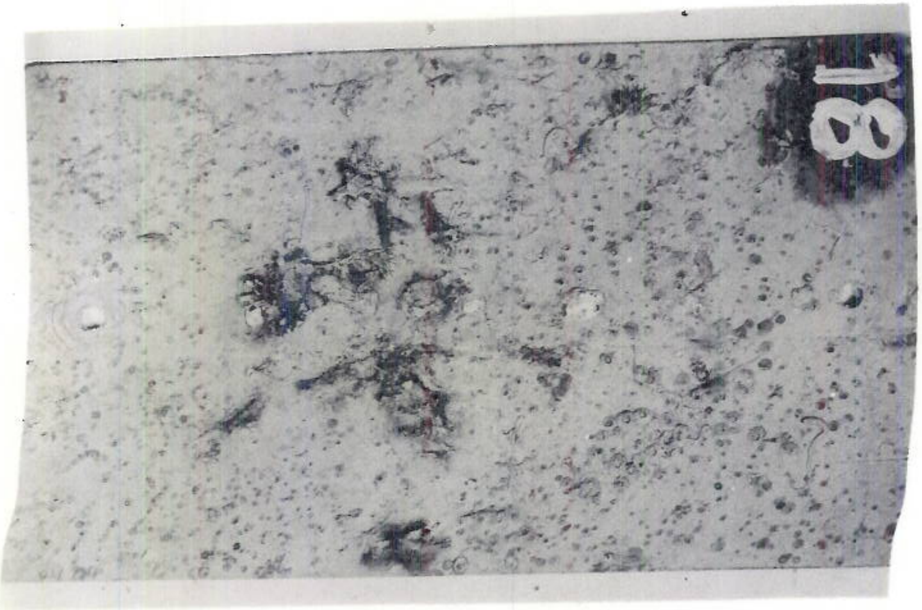

FIG. 1

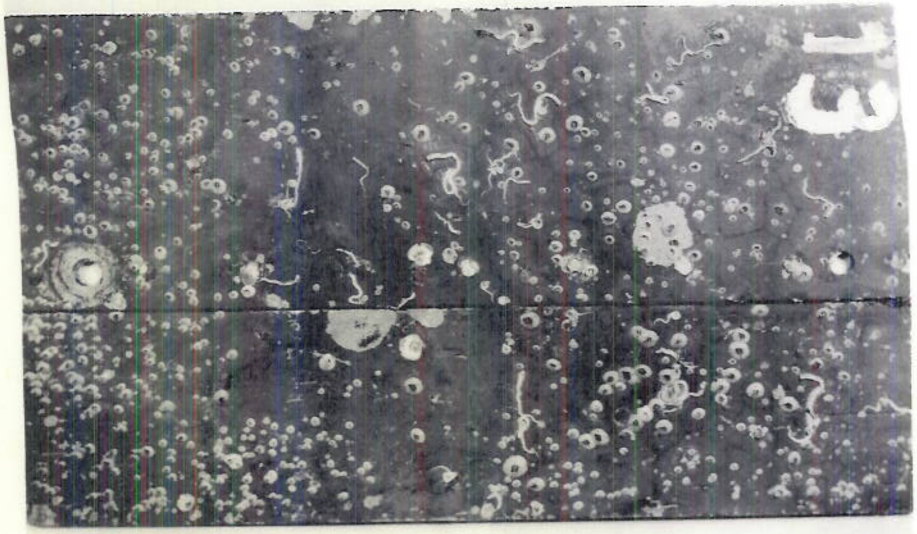

FIG. 2

PLATE 13

FIG. 1

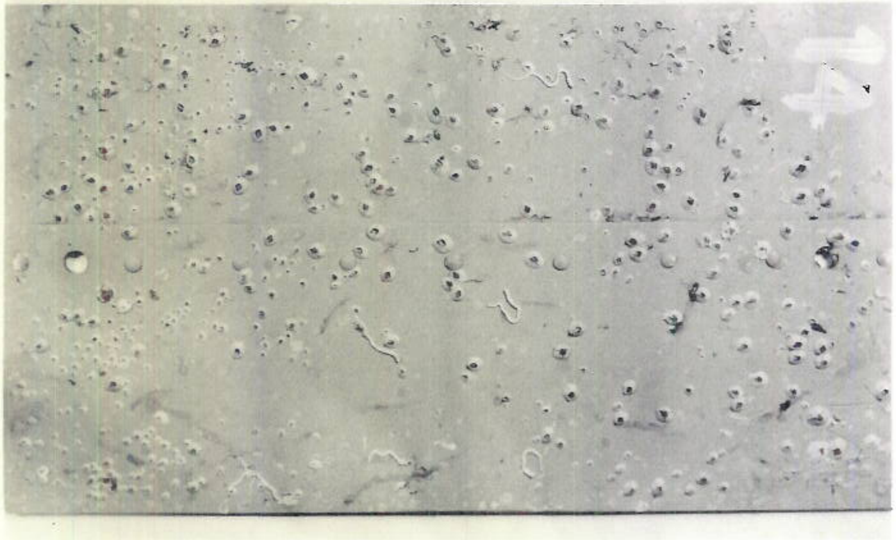

FIG. 2

PLATE 14

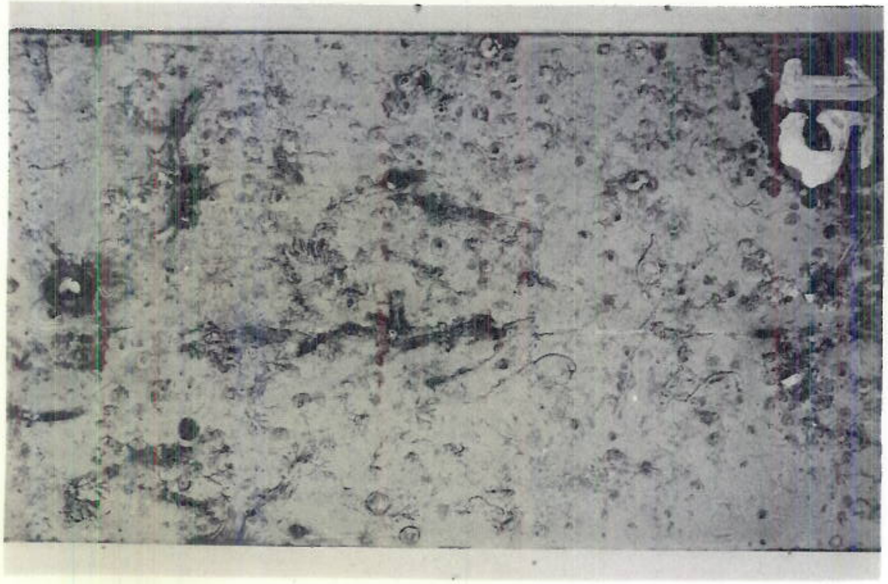

FIG. 1

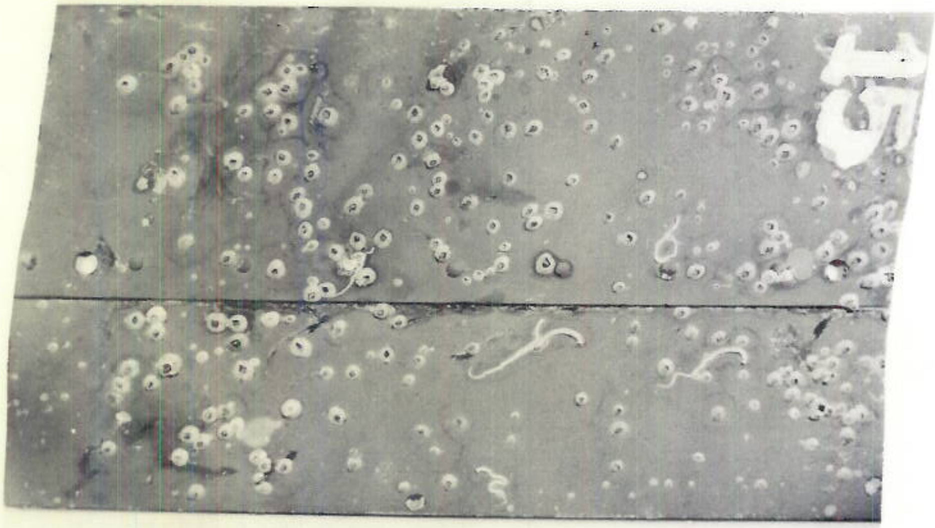

FIG. 2

PLATE 15

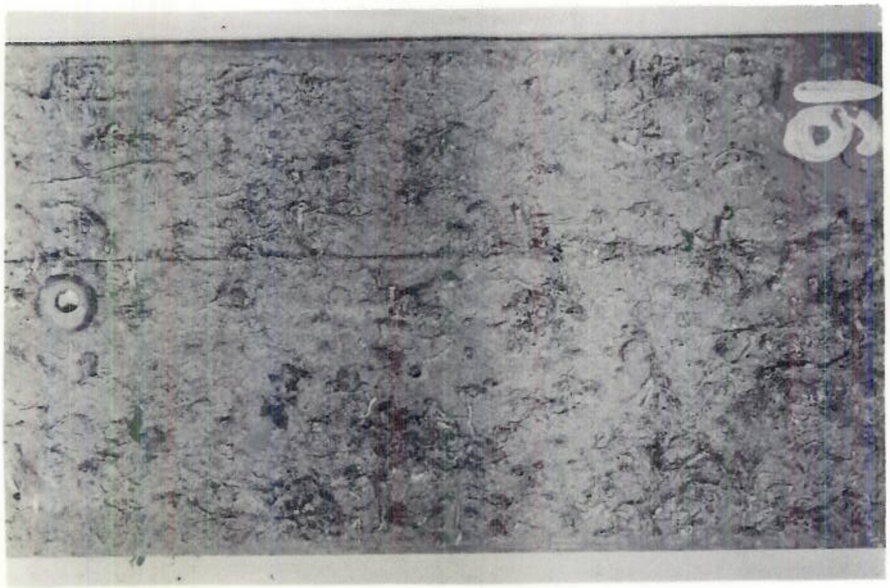

FIG. 1

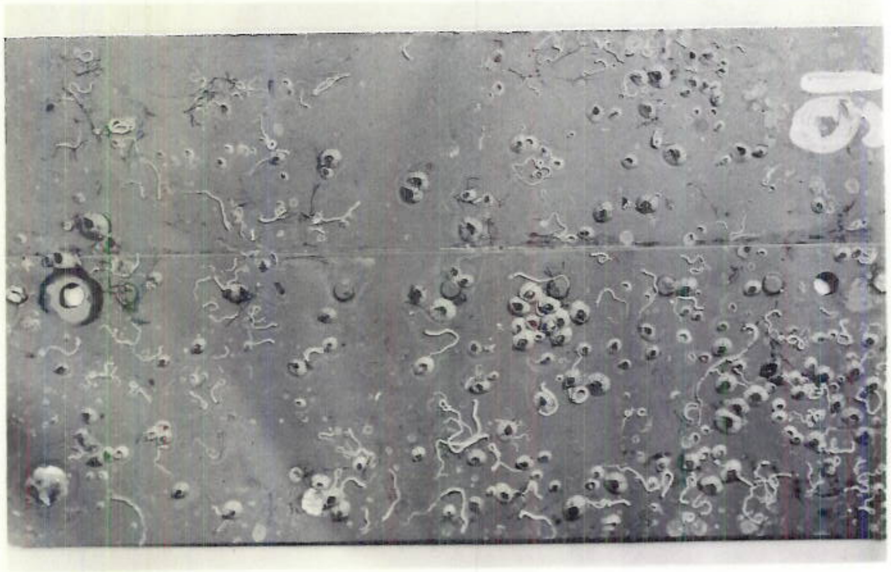

FIG. 2

PLATE 16

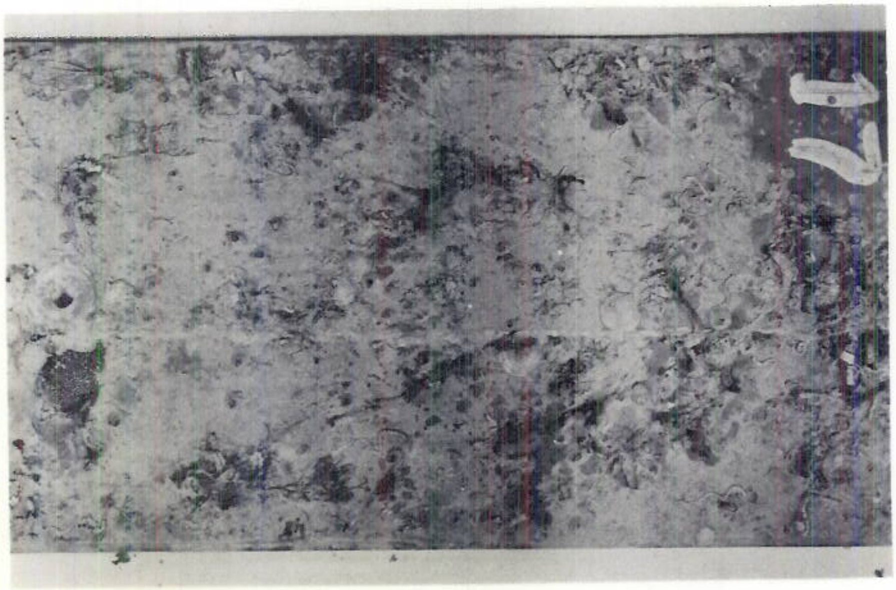

FIG. 1

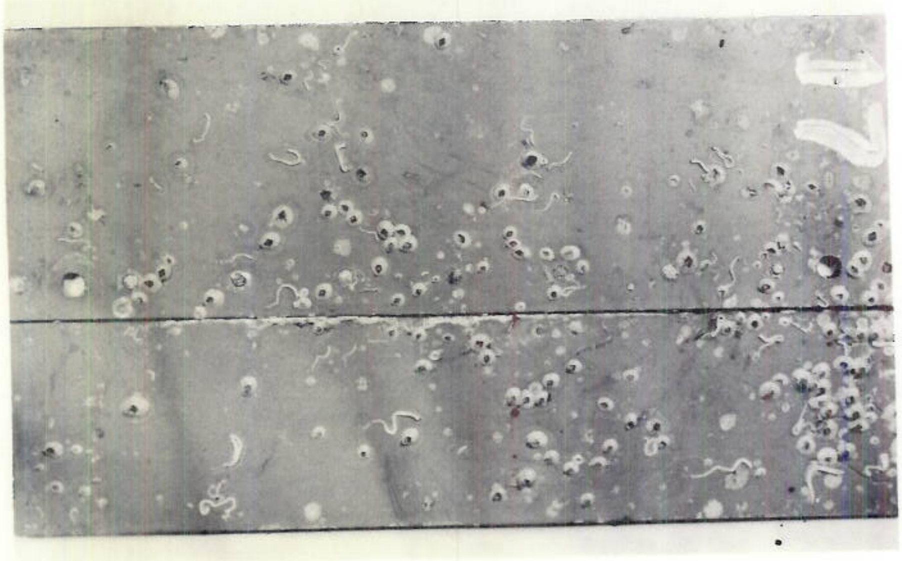

FIG. 2

PLATE 17

FIG. 1

FIG. 2

PLATE 18

FIG. 1

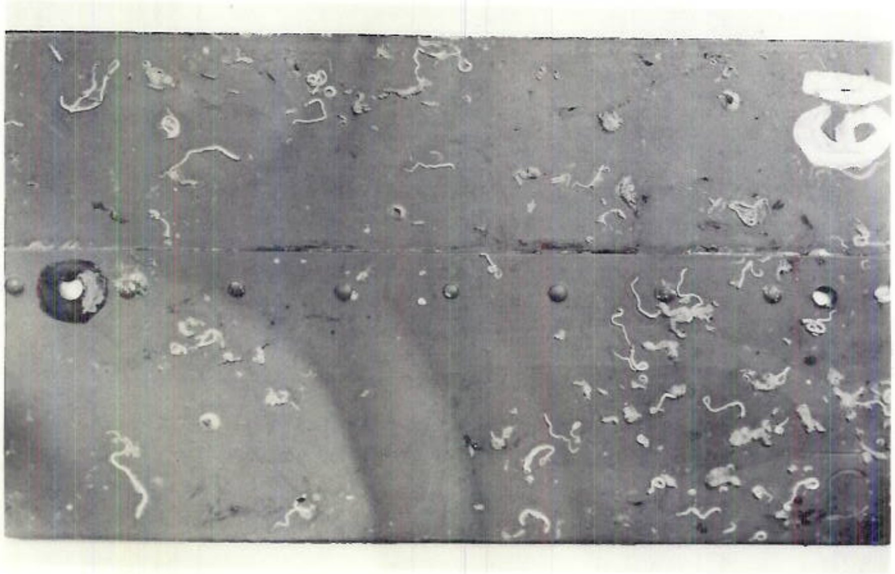

FIG. 2

PLATE 19

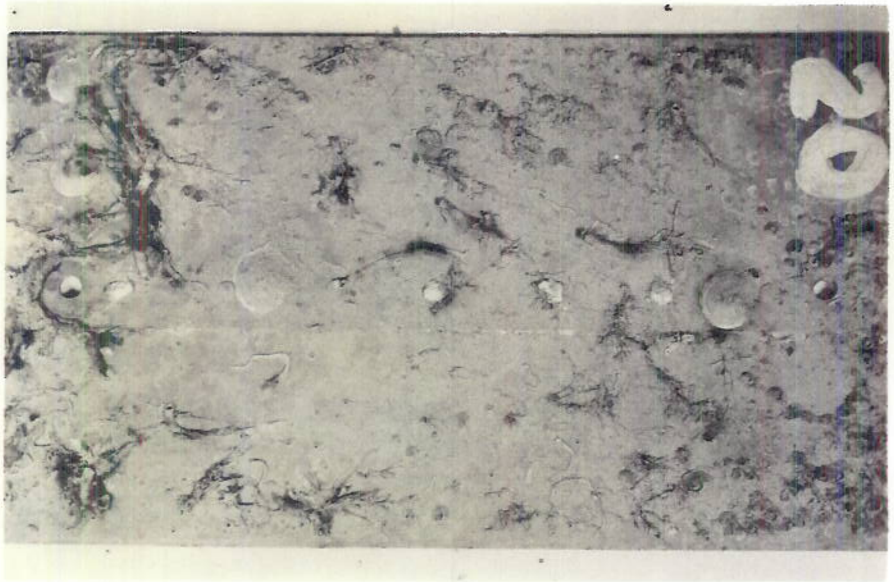

FIG. 1

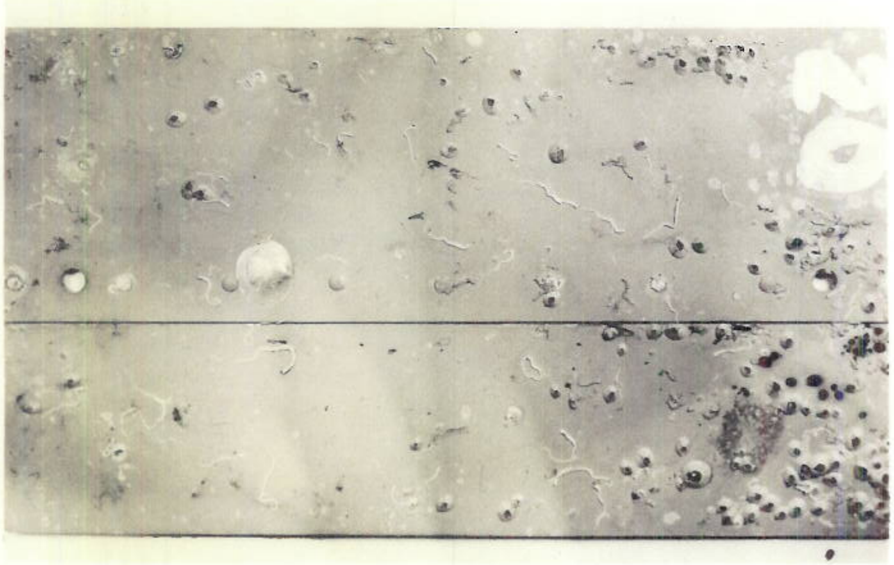

FIG. 2

PLATE 20

Appendix B includes the data for Series B compiled in exactly the same manner as described for Series A. The panels whose photographs appear in Plates 21-40 were first exposed at Miami 26 December 1940. They were removed from exposure 26 June 1941.

Formulation #50

Proprietary product marketed under the trade name of "Silosyn" pigmented with aluminum powder.

Formulation #51

Sample submitted by Valentine & Company and designated by them only as "White Anti-Fouling Paint."

Formulation #52

6.0 oz. Insl-X Resin A (solid)
6.0 oz. Zinc Cyanamide
4.5 oz. Titanium Oxide
0.187 oz. Carbon Black
12.0 oz. Toluol (from Insl-X Resin A)
4.0 oz. Solvesso #1

Solids: 51.0%
Wt/gal.: 10.0 lbs.
Viscosity: 1.29 poises

Formulation #53

6.0 oz. Insl-X Resin A (solid)
6.0 oz. Mercuric Chloride
4.5 oz. Titanium Oxide
0.187 oz. Carbon Black
12.0 oz. Toluol Solvent (from Insl-X Resin A)
7.0 oz. Solvesso #1

Solids: 46.7%
Wt/gal.: 10.1 lbs.
Viscosity: 1.443 poises

Formulation #54

6.0 oz. Insl-X Resin A (solid)
6.0 oz. Mercurous Chloride (Calomel)
4.5 oz. Titanium Oxide
0.187 oz. Carbon Black
12.0 oz. Toluol Solvent (from Insl-X Resin A)
2.9 oz. Solvesso #1

Solids: 52.8%
Wt/gal.: 10.5 lbs.
Viscosity: 1.76 poises

5.4 oz. Acryloid B-72 (solid)
0.6 oz. 1/2 sec. N.C. (dry)
6.0 oz. Zinc Cyanamide
4.5 oz. Titanium Dioxide
0.187 oz. Carbon Black
0.257 oz. Ethyl Alcohol
3.0 oz. Ethyl Acetate
5.14 oz. Butyl Acetate
1.2 oz. Butyl Alcohol
10.5 oz. Toluol
2.4 oz. Aromatic Petroleum Naphtha, Type 1
3.5 oz. Cellosolve Acetate

Solids: 39.1%
Wt/gal.: 9.6 lbs.
Viscosity: 7.095 poises

Formulation #56

5.4 oz. Insl-X Resin A (solid)
0.6 oz. Acryloid B-72 (solid)
6.0 oz. Zinc Cyanide
4.5 oz. Titanium Dioxide
0.187 oz. Carbon Black
9.0 oz. Toluol
9.5 oz. Solvesso #1

Solids: 47.9%
Wt/gal.: 9.3 lbs.
Viscosity: 1.645 poises

Formulation #57

5.4 oz. Acryloid B-72 (solid)
0.6 oz. 1/2 sec. Nitrocellulose (dry)
6.0 oz. Mercurous Chloride (calomel)
4.5 oz. Titanium Dioxide
0.187 oz. Carbon Black
0.257 oz. Ethyl Alcohol
0.50 oz. Ethyl Acetate
2.643 oz. Butyl Acetate
0.2 oz. Butyl Alcohol
8.5 oz. Toluol
0.4 oz. Aromatic Petroleum Naphtha, Type 1
3.5 oz. Cellosolve Acetate

Solids: 51.0%
Wt/gal.: 9.5 lbs.
Viscosity: 4.825 poises

5.4 oz. Insl-X Resin A (solid)
0.6 oz. Acryloid B-72 (solid)
7.12 oz. Cuprous Oxide
4.5 oz. Titanium Dioxide
0.187 oz. Carbon Black
9.0 oz. Toluol
8.4 oz. Solvesso #1

Solids:	50.5%
Wt/gal.:	10.3 lbs.
Viscosity:	2.945 poises

Formulation #59

5.4 oz. Insl-X Resin A (solid)
0.6 oz. Acryloid B-72 (solid)
4.82 oz. Cuprous Oxide
2.25 oz. Mercuric Oxide
4.5 oz. Titanium Oxide
0.187 oz. Carbon Black
9.0 oz. Toluol (from Insl-X and B-72 Resin)
17.5 oz. Solvesso #1

Solids:	35.9%
Wt/gal.:	10.2 lbs.
Viscosity:	1.016 poises

Formulation #60

5.4 oz. Insl-X Resin A (solid)
0.6 oz. Acryloid B72 (solid)
6.0 oz. Zinc Cyanamide
4.5 oz. Titanium Oxide
0.187 oz. Carbon Black
9.0 oz. Toluol (from Insl-X and B-72 Resin)
9.9 oz. Solvesso #1

Solids:	47.0%
Wt/gal.:	9.6 lbs.
Viscosity:	1.24 poises

Formulation #61

4.8 oz. Insl-X Resin A (solid)
1.2 oz. Super Beckacite 3000 (solid)
6.0 oz. Mercuric Chloride
4.5 oz. Titanium Oxide
0.187 oz. Carbon Black
9.0 oz. Toluol (from Insl-X and Super-Beckacite Resin)
9.4 oz. Solvesso #7

Solids:	47.5%
Wt/gal.:	9.9 lbs.
Viscosity:	0.092 poises

Formulation #62

4.8 oz. Insl-X Resin A (solid)
1.2 oz. Super-Beckacite 3000 (solid)
6.0 oz. Zinc Cyanamide
4.5 oz. Titanium Oxide
0.187 oz. Carbon Black
9.0 oz. Toluol (from Resin solution)
9.2 oz. Solvesso #1

Solids: 47.4%
Wt/gal.: 10.6 lbs.
Viscosity: 1.525 poises

Formulation #63

4.8 oz. Insl-X Resin A (solid)
1.2 oz. Super-Beckacite 3000 (solid)
6.0 oz. Mercurous Chloride (Calomel)
4.5 oz. Titanium Oxide
0.187 oz. Carbon Black
9.0 oz. Toluol (from Resin solutions)
4.7 oz. Solvesso #1

Solids: 56.7%
Wt/gal.: 10.9 lbs.
Viscosity: 0.722 poises

Formulation #64

4.8 oz. Insl-X Resin A (solid)
1.2 oz. Acryloid B72 (solid)
2.25 oz. Mercuric Oxide
4.82 oz. Cuprous Oxide
4.5 oz. Titanium Oxide
0.187 oz. Carbon Black
9.0 oz. Toluol (from Resin solution)
7.3 oz. Solvesso #1

Solids: 47.8%
Wt/gal.: 10.6 lbs.
Viscosity: 3.6 poises

Formulation #65

4.8 oz. Insl-X Resin A (solid)
1.2 oz. Acryloid B-72 (solid)
6.0 oz. Zinc Cyanamide
4.5 oz. Titanium Dioxide
0.187 oz. Carbon Black
9.0 oz. Toluol
17.2 oz. Solvesso #1

Solids: 39.0%
Wt/gal.: 9.4 lbs.
Viscosity: 6.26 poises

Formulation #66

5.4 oz. Acryloid B-75 (solid)
0.6 oz. 10 cps Chlorinated Rubber
2.25 oz. Mercuric Oxide
4.82 oz. Cuprous Oxide
4.50 oz. Titanium Dioxide
0.187 oz. Carbon Black
7.7 oz. Cellosolve Acetate
11.1 oz. Solvesso #3
0.9 oz. Butyl Acetate

Solids: 49.2%
Wt/gal.: 11.3 lbs.
Viscosity: 6.292 poises

Formulation #67

5.4 oz. Acryloid B-75 (solid)
0.6 oz. 10 cps Chlorinated Rubber (solid)
6.0 oz. Zinc Cyanide
4.5 oz. Titanium Dioxide
0.187 oz. Carbon Black
7.7 oz. Cellosolve Acetate
0.9 oz. Butyl Acetate
11.1 oz. Solvesso #3

Solids: 43.4%
Wt/gal.: 9.7 lbs.
Viscosity: 8.605 poises

Formulation #68

5.4 oz. Acryloid B-75 (solid)
0.6 oz. 10 cps Chlorinated Rubber (dry)
6.0 oz. Zinc Cyanamide
4.5 oz. Titanium Dioxide
0.187 oz. Carbon Black
9.0 oz. Solvesso #1
6.3 oz. Solvesso #3
0.9 oz. Butyl Acetate
7.7 oz. Cellosolve Acetate

Solids: 42.2%
Wt/gal.: 10.0 lbs.
Viscosity: 5.9 poises

Formulation #69

Control panel finished with White Gloss Lacquer, Navy Aeronautical Specification L-12.

Table II

Abrasion Resistance of Anti-Fouling Coatings - Series B

	Dry Film			Wet Film - 24 hrs. Soak		
Formulation Number	Average Wt. of Abrasive	Film Thickness in Mils	Specific Abrasion Wt./Thickness	Average Wt. of Abrasive	Film Thickness in Mils	Specific Abrasion
50	10.7	0.4	26.7	7.5	0.4	18.8
51	---	---	---	---	---	---
52	74.4	3.0	24.8	63.2	3.0	21.1
53	64.0	3.0	21.4	69.8	3.0	23.3
54	70.3	1.8	39.1	77.0	1.8	42.7
55	78.1	2.3	34.0	52.4	2.3	23.2
56	122.8	3.7	33.2	117.6	3.7	31.8
57	90.5	1.0	90.5	56.0	1.0	56.0
58	106.4	2.2	48.4	128.0	2.2	58.2
59	83.4	2.4	34.7	74.9	2.4	31.2
60	99.8	3.0	33.2	70.2	3.0	23.4
61	137.4	2.6	52.8	118.0	2.6	45.4
62	71.3	4.0	17.8	42.4	4.0	10.6
63	68.9	2.1	32.8	59.6	2.1	28.4
64	95.0	2.5	38.0	110.1	2.5	52.4
65	100.3	2.6	38.6	51.9	2.6	19.9
66	93.0	0.8	117.0	23.8	0.8	29.8
67	67.2	2.7	24.9	76.6	2.7	28.3
68	98.6	2.5	39.4	42.1	2.5	16.8
69	380.0	3.5	108.6	401.6	3.5	114.7

Table III

Weathering Characteristics of Anti-Fouling Paints - Series B

Formulation Number	Gloss in Mils: Initial	Gloss in Mils: 2 Mos.	Gloss in Mils: 5 Mos.	Panel Condition After Five Months' Roof Exposure: Color Retention	Adhesion	Chalking	Checking
50	65	45	24	Good	Good	None	None
51	50	43	5	Yellowed slightly	Poor. Too brittle.	Severe	"
52	4	2	2-1/2	Fair. Slight fading.	Excellent.	Very severe	"
53	5	-	2-1/2	Poor. Darkened.	Poor	Severe	Film ruined. Blistered & corroded.
54	21	10	4	Good	Good. Slightly brittle.	Very severe	None
55	2	1	2-1/2	Very good.	" " "	" "	"
56	5	2-1/2	2-1/2	Good	" " "	" "	"
57	15	4	3	Good. Darkened slightly.	" " "	" "	"
58	29	18	4	Darkened to gray.	Very good.	" "	"
59	28	17	4	" " "	Excellent. No change.	Exceptionally severe.	"
60	7	5	3	Faded.	Good. Slightly brittle.	" "	"
61	5	5	4	Good. Faded slightly.	Poor. Too brittle.	Very severe	"
62	7-1/2	-	5	Very poor. Faded.	Very bad.	" "	Peppered with blisters. Badly corroded.
63	20	10	2-1/2	Fair. Faded.	Poor. Too brittle.	" "	None
64	15	9	2-1/2	Faded to gray.	" " "	" "	"
65	9	5	5	Faded slightly.	" " "	" "	Mottled. Full of pinholes.
66	8	3	3	" "	" " "	" "	None
67	2	1	2	" " Fair.	Fair. " "	" "	Slight
68	2	0	2	" " "	Poor. " "	" "	None
69	70	36	20	Excellent.	" " "	Good	"

Table III

Weathering Characteristics of Anti-Fouling Paints - Series B

Formulation Number	Gloss in Mils			Panel Condition After Five Months' Roof Exposure			
	Initial	2 Mos.	5 Mos.	Color Retention	Adhesion	Chalking	Checking
50	65	45	24	Good	Good	None	None
51	50	43	5	Yellowed slightly	Poor. Too brittle.	Severe	"
52	4	2	2-1/2	Fair. Slight fading.	Excellent.	Very severe	"
53	5	-	2-1/2	Poor. Darkened.	Poor	Severe	Film ruined. Blistered & corroded.
54	21	10	4	Good	Good. Slightly brittle.	Very severe	None
55	2	1	2-1/2	Very good.	" " "	" "	"
56	5	2-1/2	2-1/2	Good	" " "	" "	"
57	15	4	3	Good. Darkened slightly.	" " "	" "	"
58	29	18	4	Darkened to gray.	Very good.	" "	"
59	28	17	4	" " "	Excellent. No change.	Exceptionally severe.	"
60	7	5	3	Faded.	Good. Slightly brittle.	" "	"
61	5	5	4	Good. Faded slightly.	Poor. Too brittle.	Very severe	"
62	7-1/2	-	5	Very poor. Faded.	Very bad.	" "	Peppered with blisters. Badly corroded.
63	20	10	2-1/2	Fair. Faded.	Poor. Too brittle.	" "	None
64	15	9	2-1/2	Faded to gray.	" " "	" "	"
65	9	5	5	Faded slightly.	" " "	" "	Mottled. Full of pinholes.
66	8	3	3	" "	" " "	" "	None
67	2	1	2	" " Fair.	Fair. " "	" "	Slight
68	2	0	2	" " "	Poor. " "	" "	None
69	70	36	20	Excellent.	" " "	Good	"

Appendix B

Appendix B includes the data for Series B compiled in exactly the same manner as described for Series A. The panels whose photographs appear in Plates 21-40 were first exposed at Miami 26 December 1940. They were removed from exposure 26 June 1941.

Formulation #50

Proprietary product marketed under the trade name of "Silosyn" pigmented with aluminum powder.

Formulation #51

Sample submitted by Valentine & Company and designated by them only as "White Anti-Fouling Paint."

Formulation #52

6.0 oz.	Insl-X Resin A (solid)
6.0 oz.	Zinc Cyanamide
4.5 oz.	Titanium Oxide
0.187 oz.	Carbon Black
12.0 oz.	Toluol (from Insl-X Resin A)
4.0 oz.	Solvesso #1

Solids: 51.0%
Wt/gal.: 10.0 lbs.
Viscosity: 1.29 poises

Formulation #53

6.0 oz.	Insl-X Resin A (solid)
6.0 oz.	Mercuric Chloride
4.5 oz.	Titanium Oxide
0.187 oz.	Carbon Black
12.0 oz.	Toluol Solvent (from Insl-X Resin A)
7.0 oz.	Solvesso #1

Solids: 46.7%
Wt/gal.: 10.1 lbs.
Viscosity: 1.443 poises

Formulation #54

6.0 oz.	Insl-X Resin A (solid)
6.0 oz.	Mercurous Chloride (Calomel)
4.5 oz.	Titanium Oxide
0.187 oz.	Carbon Black
12.0 oz.	Toluol Solvent (from Insl-X Resin A)
2.9 oz.	Solvesso #1

Solids: 52.8%
Wt/gal.: 10.5 lbs.
Viscosity: 1.76 poises

Table IV

Solution Tendencies of Paint Ingredients - Series B

Formulation Number	Ingredients	pH	Mgs. of Zn Yellow	Mgs. of Cu_2O	Mgs. of HgO	Condition of Aluminum after Removal of Paint Film
50	Al					Unaffected
51	Al					
52	Zn Cyanamide	6.6	6.06			Unaffected
53	$HgCl_2$	5.4	12.5	Solution discarded as $HgCl_2$ is too corrosive.		Badly pitted
54	Hg_2Cl_2	5.8	0.99		1.03	Unaffected
55	Zn Cyanamide	6.6	4.04			"
56	$Zn(CN)_2$	6.8	7.5			"
57	Hg_2Cl_2	6.2	4.4		4.63	"
58	Cu_2O	6.0	2.68	1.58		"
59	Cu_2O, HgO	6.0	4.37	0.23	0.721	"
60	Zn Cyanamide	6.7	4.18			"
61	"	6.8	3.57			"
62	$HgCl_2$	4.6	0.0	Solution discarded as $HgCl_2$ is too corrosive.		Badly corroded.
63	Hg_2Cl_2	5.7	2.59		1.13	Unaffected
64	Cu_2O, HgO	6.2	8.7	2.48	2.0	1 pit on each side
65	Zn Cyanamide	6.5	3.95			Unaffected
66	Cu_2O, HgO	6.2	11.0	4.05	1.85	"
67	$Zn(CN)_2$	6.8	10.67			"
68	Zn Cyanamide	6.9	9.54			"
69	L12 lacquer	--	--			--

Solution Tendencies of Paint Ingredients - Series B

Formulation Number	Ingredients	pH	Mgs. of Zn Yellow	Mgs. of Cu_2O	Mgs. of HgO	Condition of Aluminum after Removal of Paint Film
50	Al					Unaffected
51	Al					
52	Zn Cyanamide	6.6	6.06			Unaffected
53	$HgCl_2$	5.4	12.5	Solution discarded as $HgCl_2$ is too corrosive.		Badly pitted
54	Hg_2Cl_2	5.8	0.99		1.03	Unaffected
55	Zn Cyanamide	6.6	4.04			"
56	$Zn(CN)_2$	6.8	7.5			"
57	Hg_2Cl_2	6.2	4.4		4.63	"
58	Cu_2O	6.0	2.68	1.58		"
59	Cu_2O, HgO	6.0	4.37	0.23	0.721	"
60	Zn Cyanamide	6.7	4.18			"
61	"	6.8	3.57			"
62	$HgCl_2$	4.6	0.0	Solution discarded as $HgCl_2$ is too corrosive.		Badly corroded.
63	Hg_2Cl_2	5.7	2.59		1.13	Unaffected
64	Cu_2O, HgO	6.2	8.7	2.48	2.0	1 pit on each side
65	Zn Cyanamide	6.5	3.95			Unaffected
66	Cu_2O, HgO	6.2	11.0	4.05	1.85	"
67	$Zn(CN)_2$	6.8	10.67			"
68	Zn Cyanamide	6.9	9.54			"
69	L12 lacquer	--	--			--

FIG. 1

FIG. 2

PLATE 21

FIG. 1

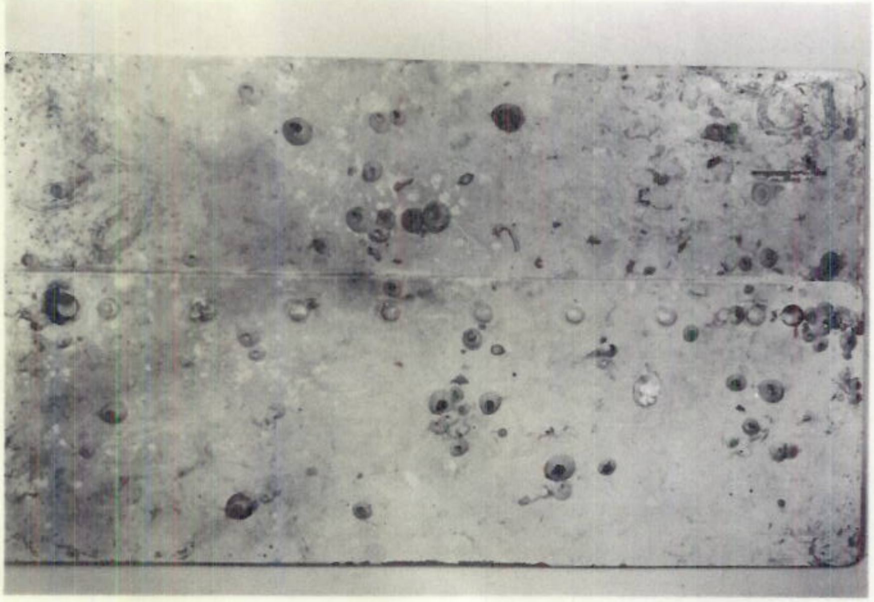

FIG. 2

PLATE 22

FIG. 1

FIG. 2

PLATE 23

FIG. 1

FIG. 2

PLATE 24

FIG. 1

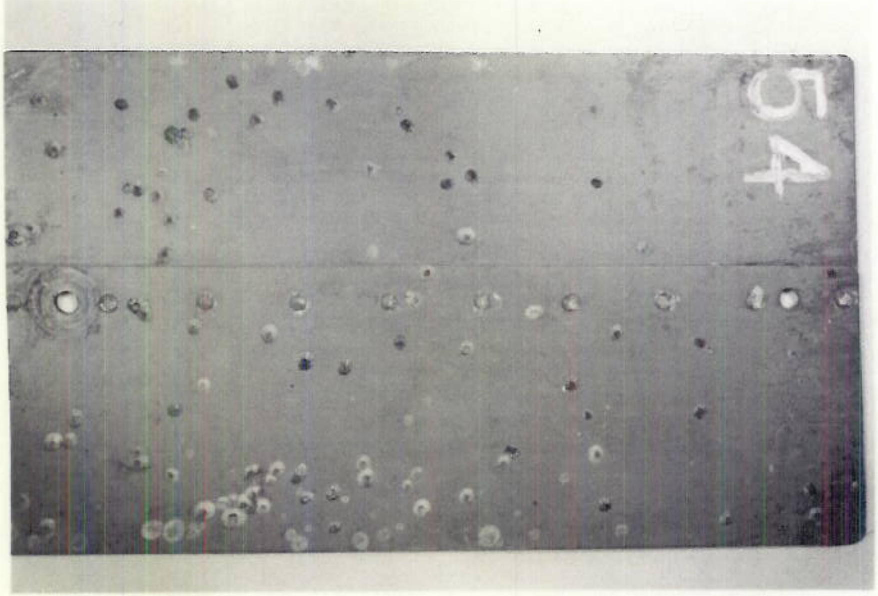

FIG. 2

PLATE 25

FIG. 1

FIG. 2

PLATE 26

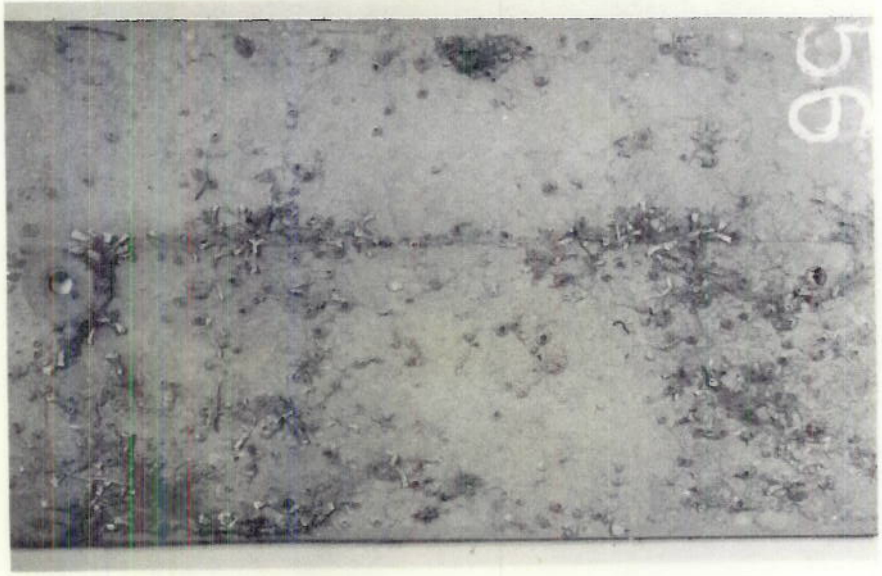

FIG. 1

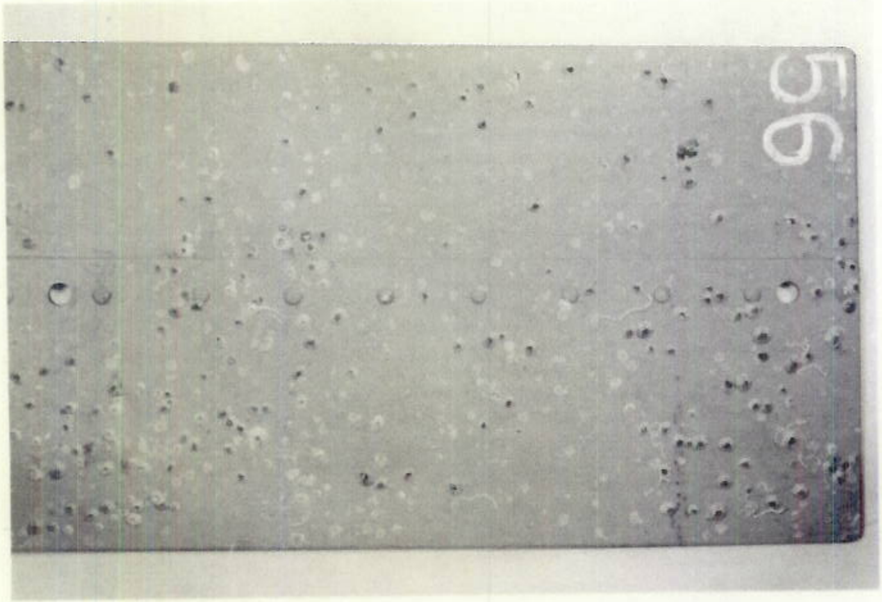

FIG. 2

PLATE 27

FIG. 1

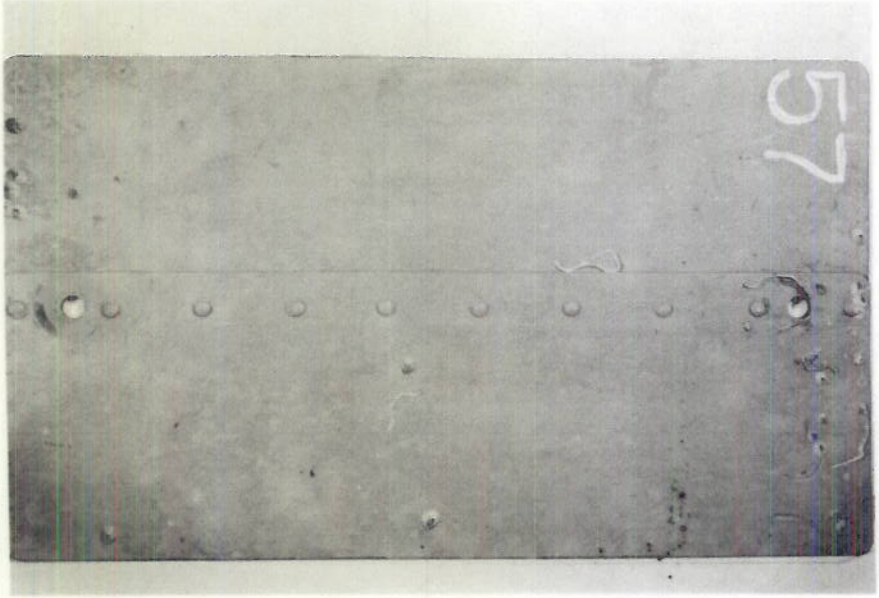

FIG. 2

PLATE 28

FIG. 1

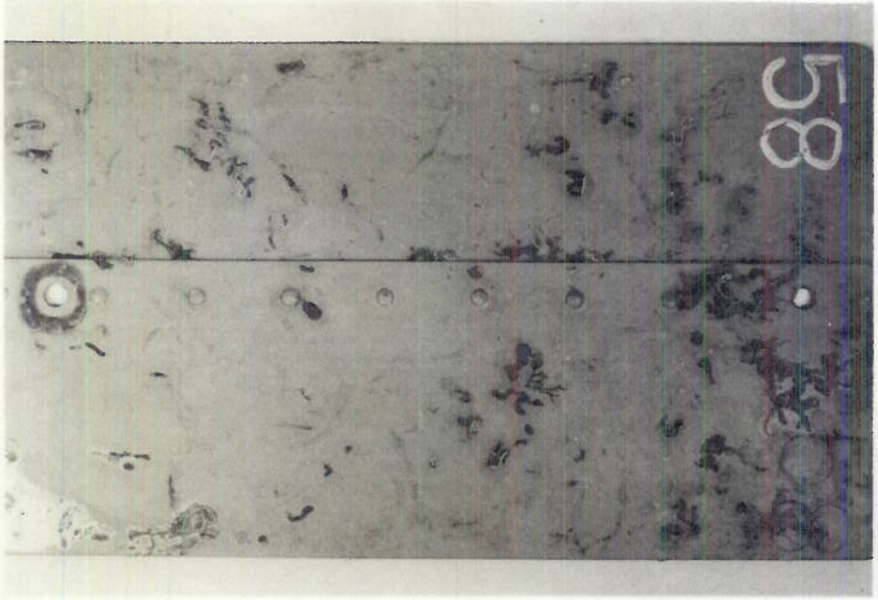

FIG. 2

PLATE 29

FIG. 1

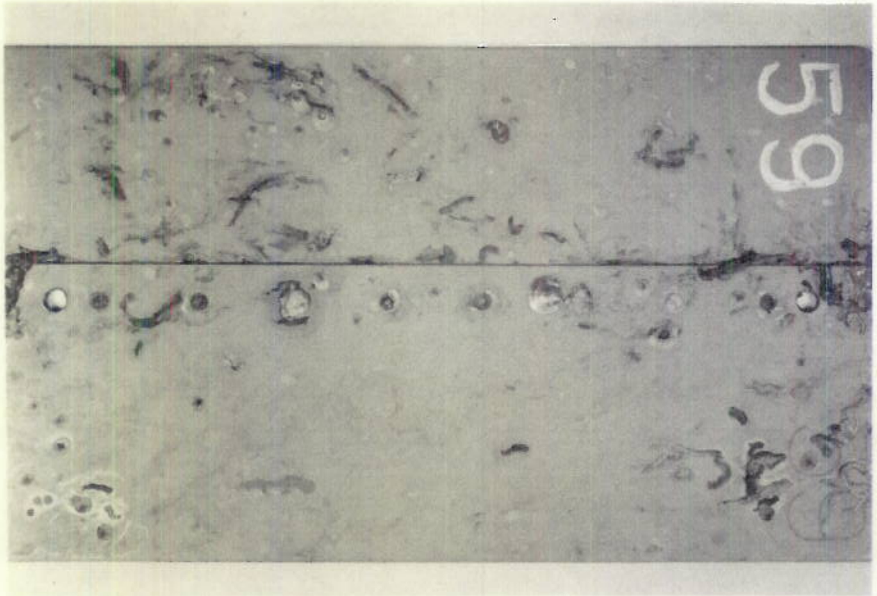

FIG. 2

PLATE 30

FIG. 1

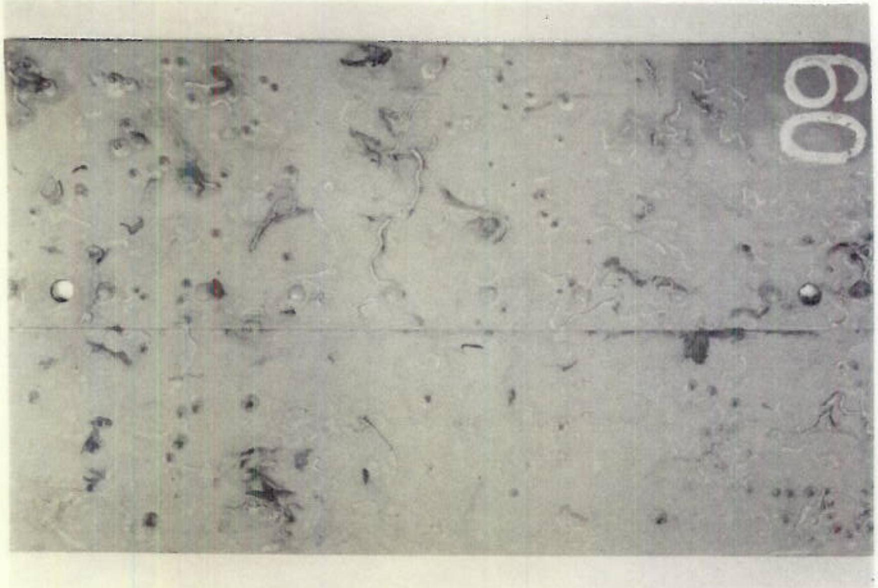

FIG. 2

PLATE 31

FIG. 1

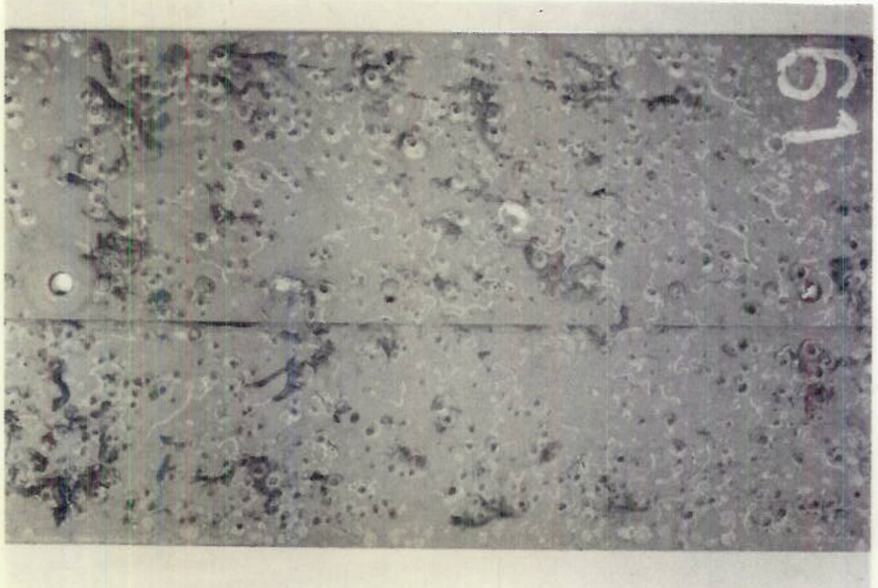

FIG. 2

PLATE 32

FIG. 1

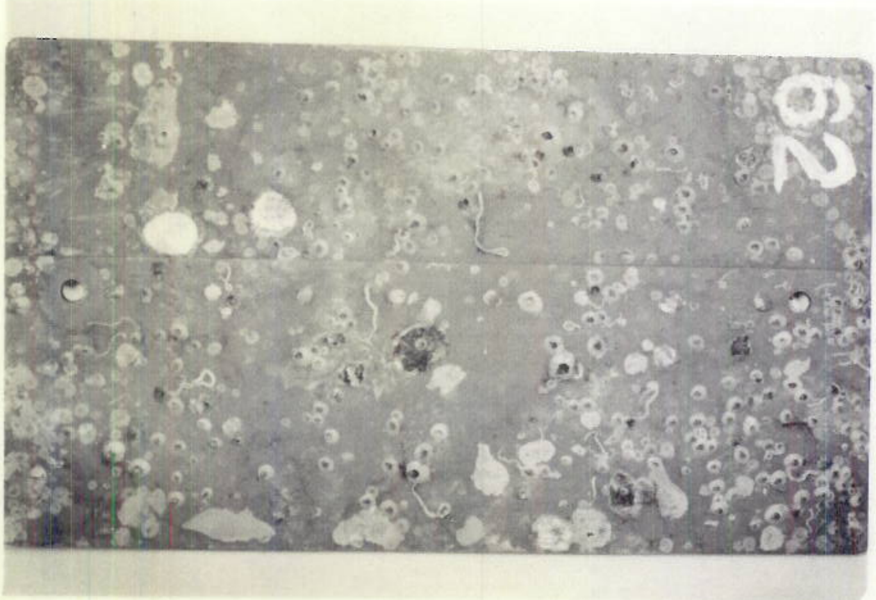

FIG. 2

PLATE 33

FIG. 1

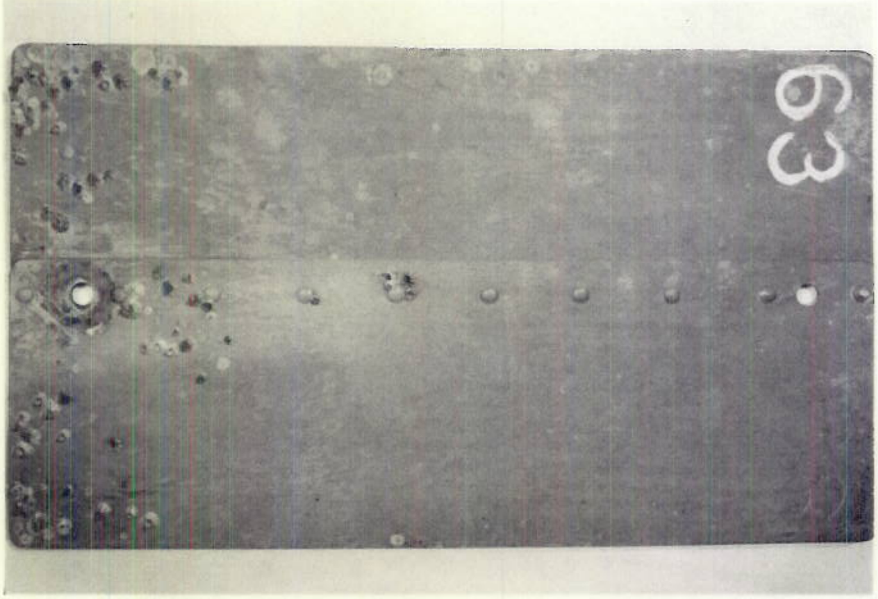

FIG. 2

PLATE 34

FIG. 1

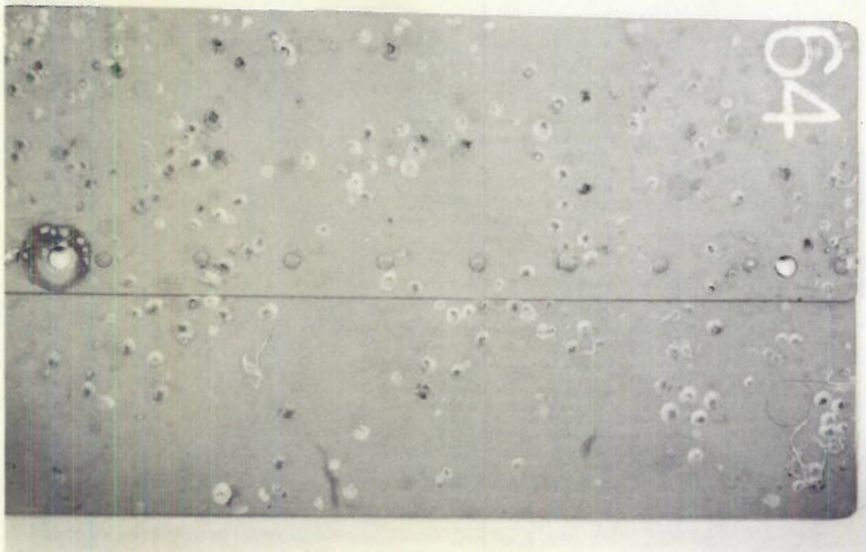

FIG. 2

PLATE 35

FIG. 1

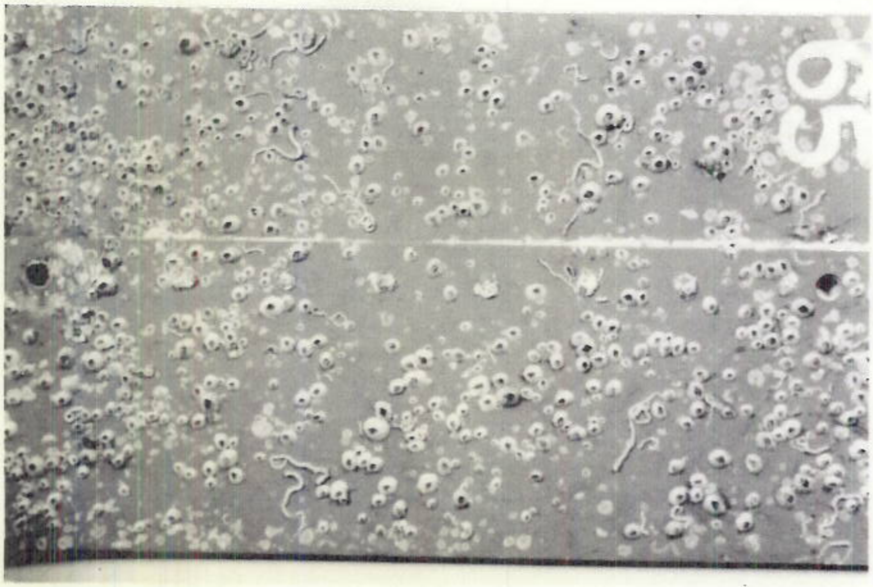

FIG. 2

PLATE 36

FIG. 1

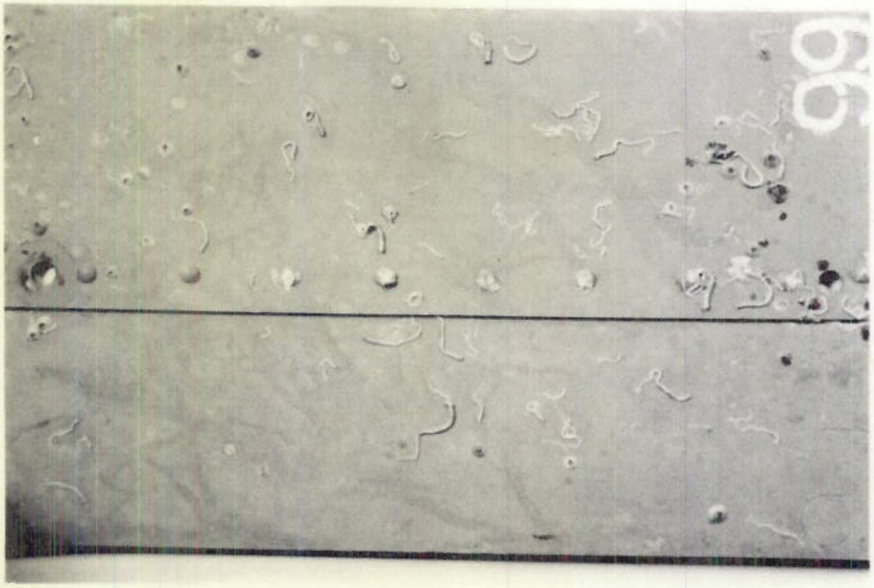

FIG. 2

PLATE 37

FIG. 1

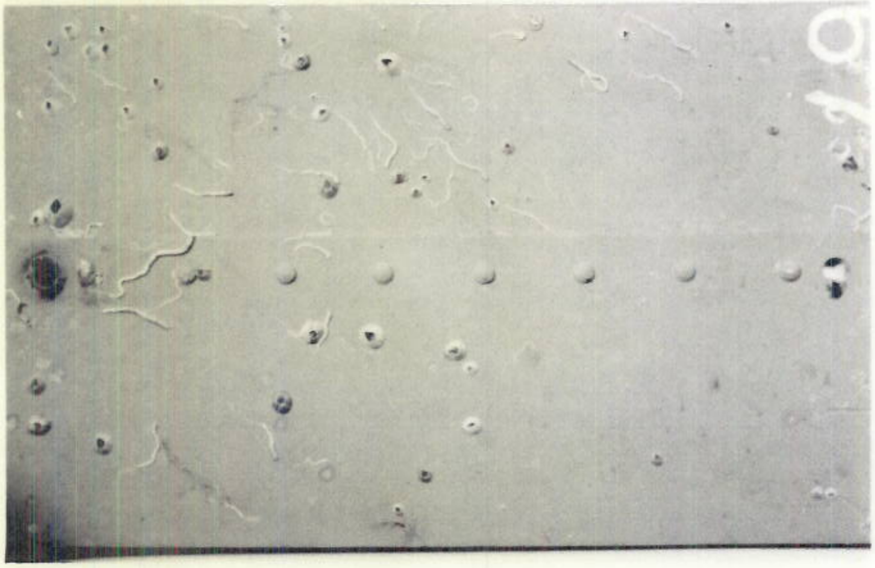

FIG. 2

PLATE 38

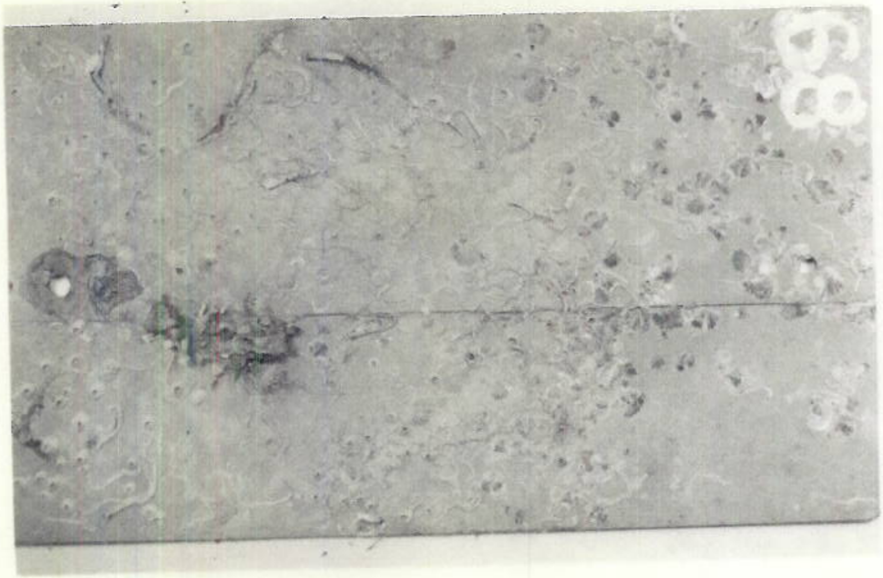

FIG. 1

FIG. 2

PLATE 39

FIG. 1

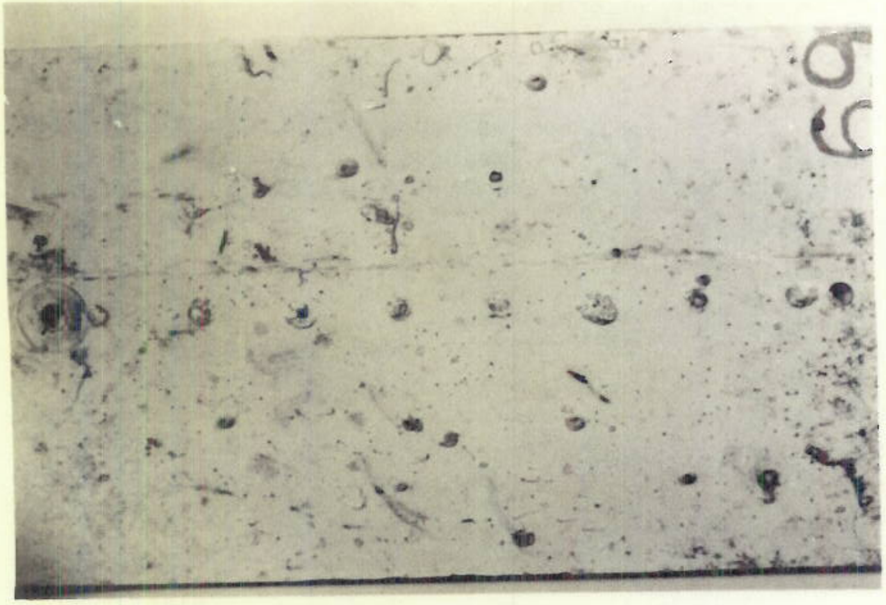

FIG. 2

PLATE 40

Appendix C

The data pertinent to the samples included in Series C are presented in Appendix C in detail. The arrangement here is identical with that used in Appendices A and B.

Series C was first exposed at Miami 28 January 1941, and was removed from exposure racks 28 July 1941.

Formulations numbers 41-46 inclusive were prepared and submitted by the Bakelite Corporation in connection with the work they are doing on anti-fouling properties. The following formulae were furnished the Laboratory simultaneously with the finished panels and with samples of the paint. As in the case of panels prepared in this Laboratory, the Bakelite formulations were applied over anodized aluminum alloy (24 ST) to which had been applied a first coat and finally a full coat of zinc chromate primer P-27b-2. The complete schedule for this series of panels is as follows:

Series No.	1st Coat	2nd Coat	3rd Coat
41	P-27b-2	1190-5J	1190-5J
42	"	1190-9B	1190-9B
43	"	1190-10C	1190-10C
44	"	1190-9B	1190-5J
45	"	1190-9B	1190-9B
46	"	1190-9B	1190-10C

The compositions of the paint listed in the above group were formulated as follows:

No. 1190-5J

XV-1657 (rapid drying phenolic resin - chinawood oil varnish)	- 90 parts by wt.
Halowax (chlorinated naphthalene)	- 10 parts by wt.
Nickel flake	- 50 parts by wt.

No. 1190-9B

BK-3962 Dispersion Resin (same as is used in P-27b primer)	- 45 parts by wt.
Xylol	- 45 parts by wt.
Cuprous Oxide	- 4.5 parts by wt.
Mercuric Oxide	- 1.2 parts by wt.
Halowax	- 4.3 parts by wt.

The data pertinent to the samples included in Series C are presented in Appendix C in detail. The arrangement here is identical with that used in Appendices A and B.

Series C was first exposed at Miami 28 January 1941, and was removed from exposure racks 28 July 1941.

Formulations numbers 41-46 inclusive were prepared and submitted by the Bakelite Corporation in connection with the work they are doing on anti-fouling properties. The following formulae were furnished the Laboratory simultaneously with the finished panels and with samples of the paint. As in the case of panels prepared in this Laboratory, the Bakelite formulations were applied over anodized aluminum alloy (24 ST) to which had been applied a first coat and finally a full coat of zinc chromate primer P-27b-2. The complete schedule for this series of panels is as follows:

Series No.	1st Coat	2nd Coat	3rd Coat
41	P-27b-2	1190-5J	1190-5J
42	"	1190-9B	1190-9B
43	"	1190-10C	1190-10C
44	"	1190-9B	1190-5J
45	"	1190-9B	1190-9B
46	"	1190-9B	1190-10C

The compositions of the paint listed in the above group were formulated as follows:

No. 1190-5J

XV-1657 (rapid drying phenolic resin - chinawood oil varnish)	- 90 parts by wt.
Halowax (chlorinated naphthalene)	- 10 parts by wt.
Nickel flake	- 50 parts by wt.

No. 1190-9B

BK-3962 Dispersion Resin (same as is used in P-27b primer)	- 45 parts by wt.
Xylol	- 45 parts by wt.
Cuprous Oxide	- 4.5 parts by wt.
Mercuric Oxide	- 1.2 parts by wt.
Halowax	- 4.3 parts by wt.

No. 1190-10C

BV-1803 (a baking type of phenolic resin varnish)	- 41.6 parts by wt.
Toluol	- 6.2 " " "
Denatured alcohol	- 6.2 " " "
Cuprous Oxide	- 8.3 " " "
Mercuric Oxide	- 3.3 " " "
Asbestine	- 1.1 " " "
Nickel Flake	- 33.3 " " "

Formulations 70 to 75, inclusive, were submitted by the Goodyear Tire and Rubber Company. The formulae for these compositions have not been disclosed to the Laboratory.

Formulation #81

Aluminized silosyn which was included in this series as a control.

Formulation #82

Submitted by the Naval Aircraft Factory as a control and for comparative tests.

Formulation #83

6.4 oz. Insl-X Resin A (dry)
1.6 oz. Acryloid B-72 (dry)
8.0 oz. Cuprous Oxide
4.0 oz. Copper Resinate
6.0 oz. Titanium Dioxide
0.25 oz. Carbon Black
13.60 oz. Toluol
15.06 oz. Solvesso #1

Solids: 47.7%
Wt/gal.: 9.4 lbs.
Viscosity: 4.495 poises

Formulation #84

5.4 oz. Insl-X Resin A (dry)
0.6 oz. Acryloid B-72 (dry)
6.0 oz. Mercuric Chloride
4.5 oz. Titanium Oxide
0.187 oz. Carbon Black
9.0 oz. Toluol
9.6 oz. Solvesso #1

Solids: 47.2%
Wt/gal.: 9.9 lbs.
Viscosity: 1.73 poises

BV-1803 (a baking type of phenolic resin varnish)	- 41.6 parts by wt.
Toluol	- 6.2 " " "
Denatured alcohol	- 6.2 " " "
Cuprous Oxide	- 8.3 " " "
Mercuric Oxide	- 3.3 " " "
Asbestine	- 1.1 " " "
Nickel Flake	- 33.3 " " "

Formulations 70 to 75, inclusive, were submitted by the Goodyear Tire and Rubber Company. The formulae for these compositions have not been disclosed to the Laboratory.

Formulation #81

Aluminized silosyn which was included in this series as a control.

Formulation #82

Submitted by the Naval Aircraft Factory as a control and for comparative tests.

Formulation #83

6.4 oz.	Insl-X Resin A (dry)
1.6 oz.	Acryloid B-72 (dry)
8.0 oz.	Cuprous Oxide
4.0 oz.	Copper Resinate
6.0 oz.	Titanium Dioxide
0.25 oz.	Carbon Black
13.60 oz.	Toluol
15.06 oz.	Solvesso #1

Solids: 47.7%
Wt/gal.: 9.4 lbs.
Viscosity: 4.495 poises

Formulation #84

5.4 oz.	Insl-X Resin A (dry)
0.6 oz.	Acryloid B-72 (dry)
6.0 oz.	Mercuric Chloride
4.5 oz.	Titanium Oxide
0.187 oz.	Carbon Black
9.0 oz.	Toluol
9.6 oz.	Solvesso #1

Solids: 47.2%
Wt/gal.: 9.9 lbs.
Viscosity: 1.73 poises

5.4 oz. Acryloid B-75 (solid)
0.6 oz. 10 cps Chlorinated Rubber (dry)
6.0 oz. Mercurous Chloride (Calomel)
4.5 oz. Titanium Oxide
0.187 oz. Carbon Black
6.8 oz. Cellosolve Acetate
0.9 oz. Butyl Acetate
7.5 oz. Solvesso #1
6.3 oz. Solvesso #3

Solids: 43.8%
Wt/gal.: 9.4 lbs.
Viscosity: 1.355 poises

Formulation #86

4.0 oz. Acryloid A-10 (dry)
0.66 oz. Dibutyl Phthalate
4.0 oz. Cuprous Oxide
2.0 oz. Copper Resinate
12.0 oz. Cellosolve Acetate (from resin solution)

Solids: 47.5%
Wt/gal.: 9.8 lbs.
Viscosity: 5.123 poises

Formulation #87

The 100 gallon formula is as follows:

106.8 lbs. Mercurous Chloride (Calomel)
135.8 lbs. Titanium Oxide
54.2 lbs. Zinc Oxide
0.94 lbs. Blue Toner
78.7 lbs. Chlorinated Rubber (125 cps)
53.4 lbs. Copper Resinate
560.0 lbs. Xylol

Solids: 44.7%
Wt/gal.: 9.9 lbs.
Viscosity: 0.769 poises

Formulation #88

5.4 oz. Insl-X Resin A (dry)
0.6 oz. Acryloid B-72 (dry)
6.0 oz. Cuprous Oxide
1.125 oz. Zinc Yellow
4.5 oz. Titanium Oxide
0.375 oz. Carbon Black
9 oz. Toluol
11.3 oz. Solvesso #1

Solids: 47.0%
Wt/gal.: 10.2 lbs.
Viscosity: 21.3 poises

Table II

Abrasion Resistance of Anti-Fouling Coatings - Series C

Formulation Number	Dry Film			Wet Film - 24 hours soak		
	Average Wt. of Abrasive	Film Thickness in Mils	Specific Abrasion Wt/Thickness	Average Wt. of Abrasive	Film Thickness in Mils	Specific Abrasion Wt/Thickness
41	328.6	10.3	25.3	247.3	10.3	24.0
42	182.3	3.2	57.0	181.5	3.2	56.8
43	94.6	4.4	21.5	72.3	4.4	16.5
44	112.6	7.1	15.9	120.2	7.1	16.9
45	142.3	2.3	61.9	89.3	2.3	36.7
46	192.0	6.5	29.5	118.5	6.5	18.2
70	29.6	1.5	13.1	6.9	1.5	4.6
71	15.3	1.1	13.9	5.4	1.1	4.9
72	17.2	0.7	24.6	6.5	0.7	9.3
73	63.0	0.7	90.0	25.5	0.7	36.4
74	18.3	0.9	20.3	28.4	0.9	31.6
75	20.5	0.9	22.8	24.5	0.9	27.2
81	10.7	0.4	26.7	7.5	0.4	18.8
82	76.3	1.7	44.9	69.7	1.7	41.0
83	32.2	1.4	23.0	28.4	1.4	20.3
84	39.6	1.9	20.8	N.G.	1.9	N.G.
85	69.3	1.9	36.5	66.2	1.9	34.8
86	47.0	2.1	22.4	39.5	2.1	18.8
87	35.1	2.5	14.0	31.8	2.5	12.7
88	29.8	0.6	49.7	21.9	0.6	36.5

Table III

Weathering Characteristic of Anti-Fouling Paints - Series C

Formulation Number	Gloss in Mils			Panel Condition After Five Months' Roof Exposure			
	Initial	2 Mos.	5 Mos.	Color Retention	Adhesion	Chalking	Checking
41	--	14	8	Darkened considerably.	Excellent.	None	None
42	9	0	2	" Poor	Fair. Brittle.	None	Bad
43	10	9	-	Poor.	Excellent.	None	None
44	85	42	10	Fair. Darkened.	"	"	"
45	95	52	0	Poor. Darkened. Faded.	Good	"	Considerable on back.
46	--	6	7	Poor.	Very poor.	None	Blisters
70	68	1	3	Poor. Darkened.	Extremely poor.	Slight	None
71	48	1	3	" "	" "	"	"
72	69	1	1	" "	" "	"	Considerable on edges
73	95	60	65	Fair. Faded.	" "	"	Bad
74	65	1	1	Poor. Mottled.	" "	Severe	Considerable
75	65	1	2	" "	Completely unsatisfactory.	"	"
81	65	45	24	Good.	Good.	None	None
82	6	2	2	Poor. Faded.	Excellent.	Very severe.	Extremely small.
83	18	3	2	" "	Very good.	Severe	None
84	7	4	--	Fair. Some fading.	Good.	"	Badly blistered and corroded.
85	18	4	4	Good. " "	Excellent	Very severe.	None
86	71	9	9	Poor. " "	Poor. Too brittle.	Slight	Evidence of beginning
87	14	6	6	Fair. " "	Only fair.	Severe	None
88	18	10	9	Poor. " "	Excellent.	Severe	None

Table IV

Solution Tendencies of Paint Ingredients - Series C

Formulation Number	Active Ingredients	Solution Analysis				Condition of Aluminum after Removal of Paint Film
		pH	Mgs. of Zn Yellow	Mgs. of Cu_2O	Mgs. of HgO	
41	Halowax Nickel	6.5	0.0			Unaffected
42	Cu_2O, HgO	6.4	1.27		0.876	"
43	Cu_2O, HgO	6.5	2.49			"
44	Cu_2O, HgO	6.6	2.40		0.432	"
45	Cu_2O, HgO	6.4	1.79		1.08	"
46	Cu_2O, HgO	6.7	1.74		0.432	"
70	Unknown	6.7	4.99			"
71	Unknown	6.9	7.10			"
72	"	6.8	6.77			"
73	"	6.4	1.46			"
74	"	6.5	4.28			"
75	"	6.7	5.08			"
81	Silosyn, Al	6.5	1.74			?
82	Hg_2Cl_2	7.0	3.53		1.4	Unaffected
83	Cu_2O Cu Resinate	6.9	5.55	0.63		"
84	$HgCl_2$	6.1	9.68	Solution discarded		Badly corroded
85	Hg_2Cl_2	5.6	0.54		1.3	Unaffected
86	Cu_2O Cu Resinate	6.2	14.85	5.29		Slightly pitted
87	Hg_2Cl_2 Cu Resinate	6.0	15.28	1.3	0.32	Unaffected
88	Cu_2O	5.7	24.11	0.24		"

FIG. 1

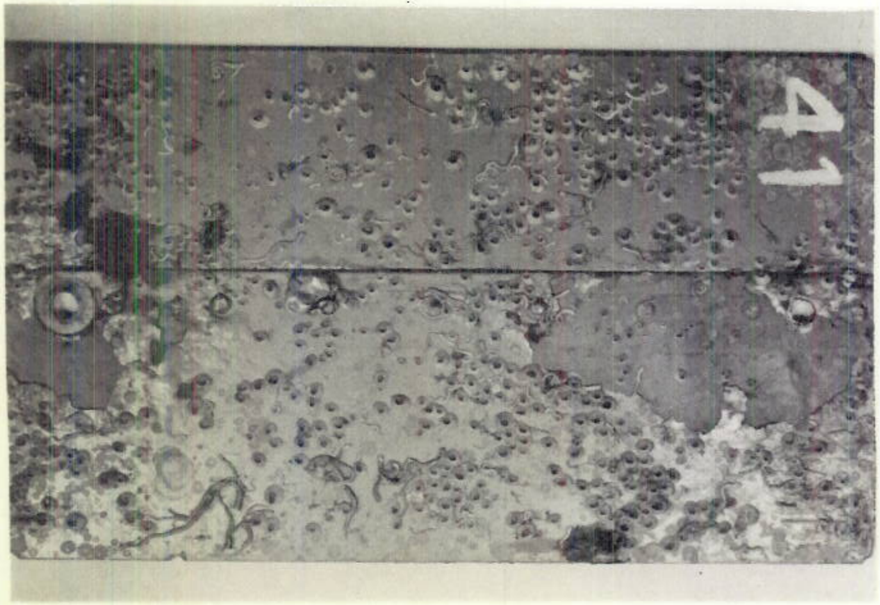

FIG. 2

PLATE 41

FIG. 1

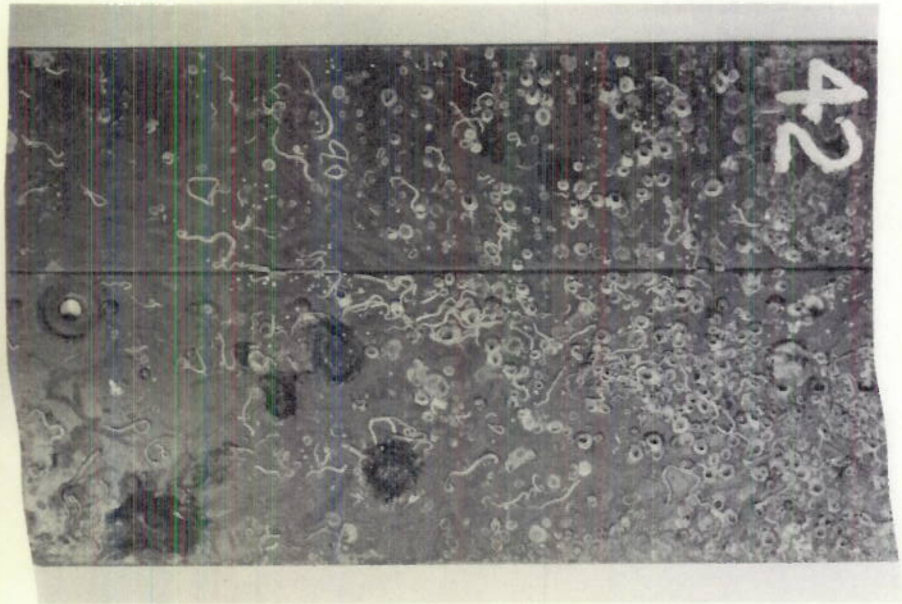

FIG. 2

PLATE 42

FIG. 1

FIG. 2

PLATE 43

FIG. 1

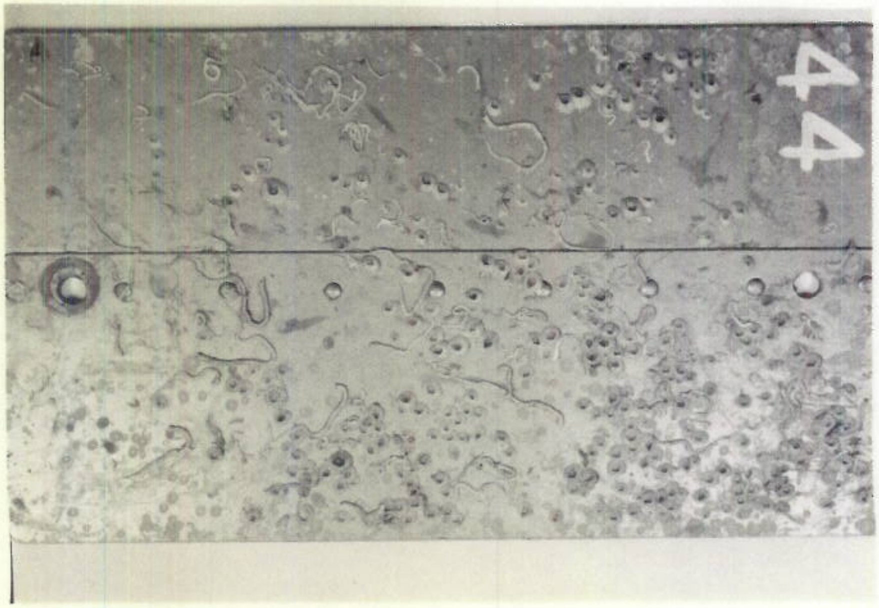

FIG. 2

PLATE 44

FIG. 1

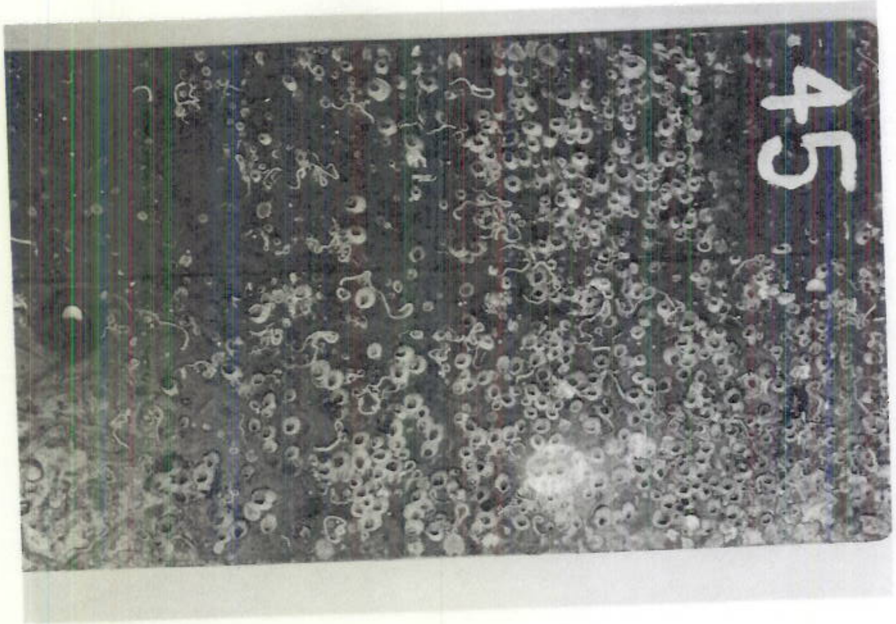

FIG. 2

PLATE 45

FIG. 1

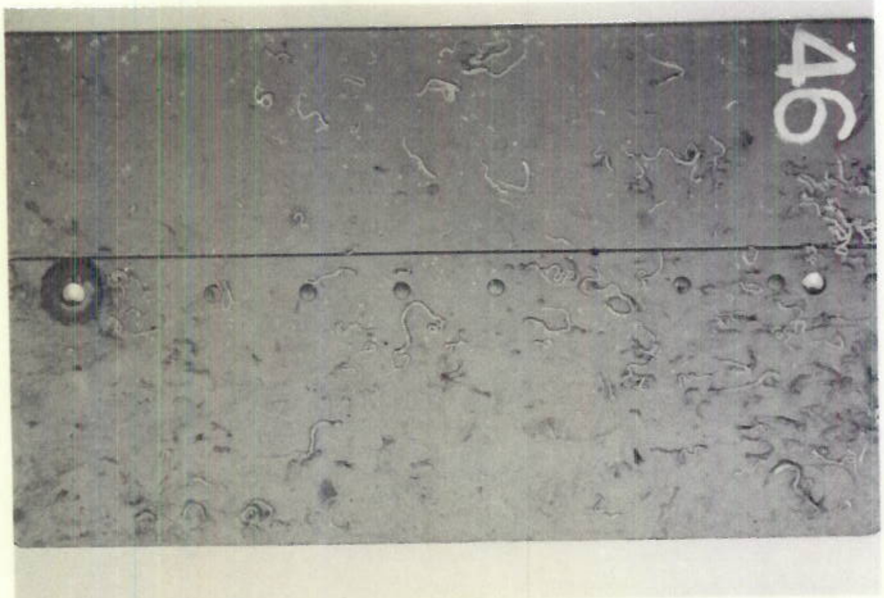

FIG. 2

PLATE 46

FIG. 1

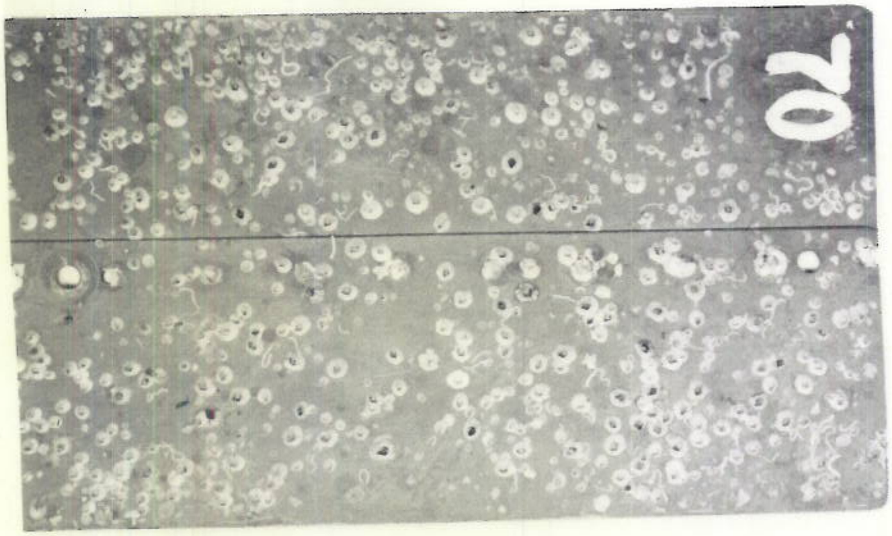

FIG. 2

PLATE 47

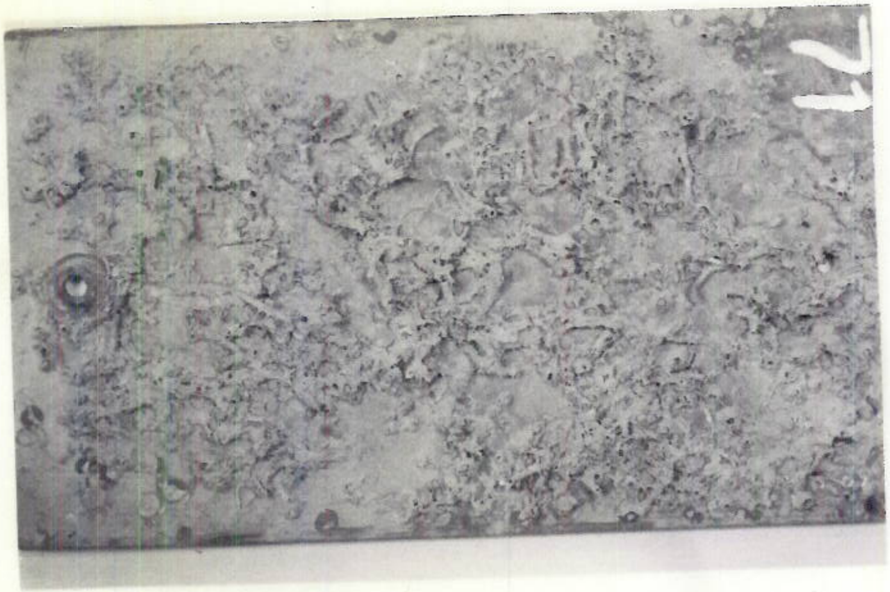

FIG. 1

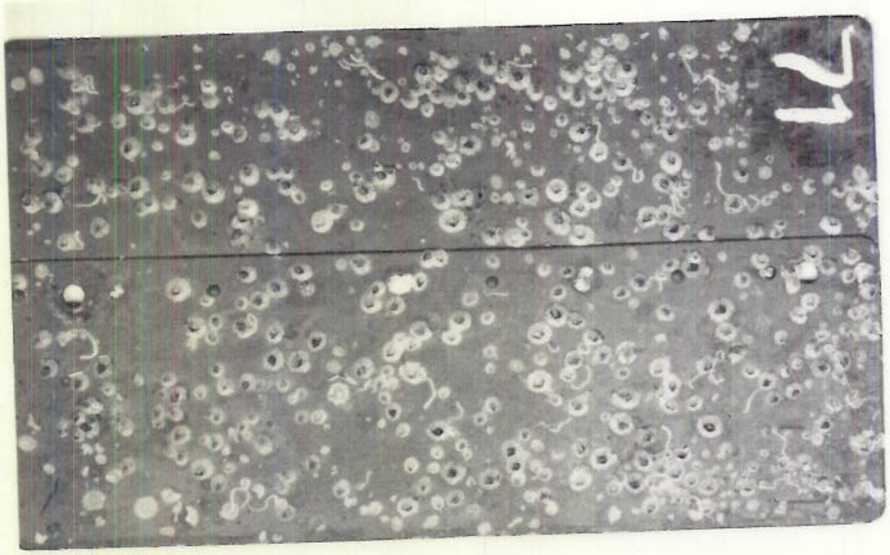

FIG. 2

PLATE 48

FIG. 1

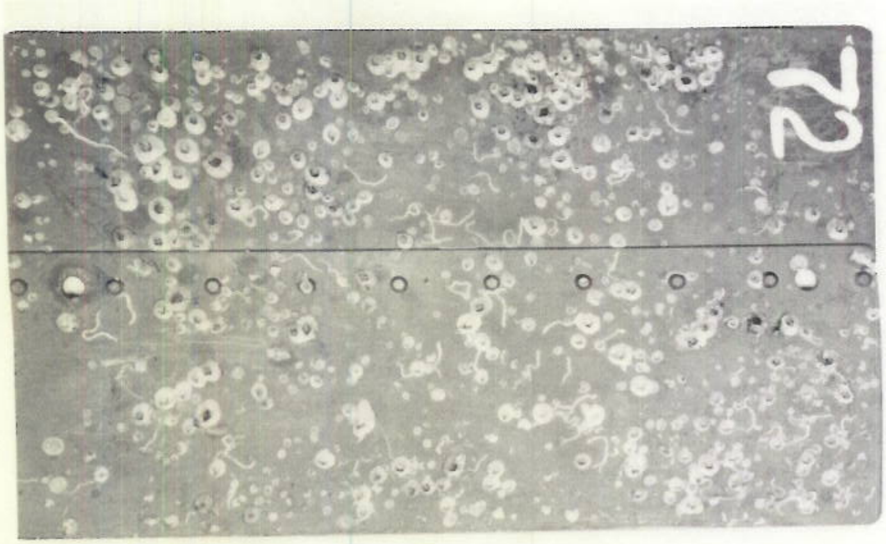

FIG. 2

PLATE 49

FIG. 1

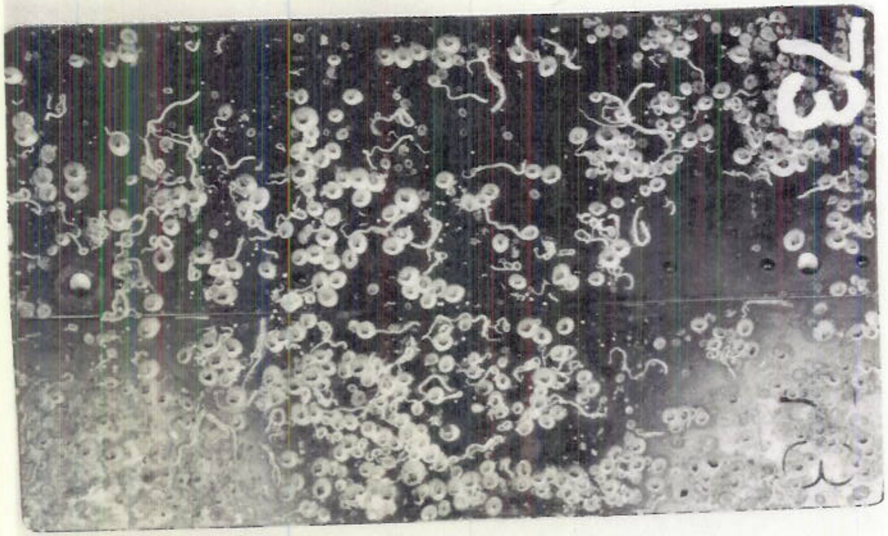

FIG. 2

PLATE 50

FIG. 1

FIG. 2

PLATE 51

FIG. 1

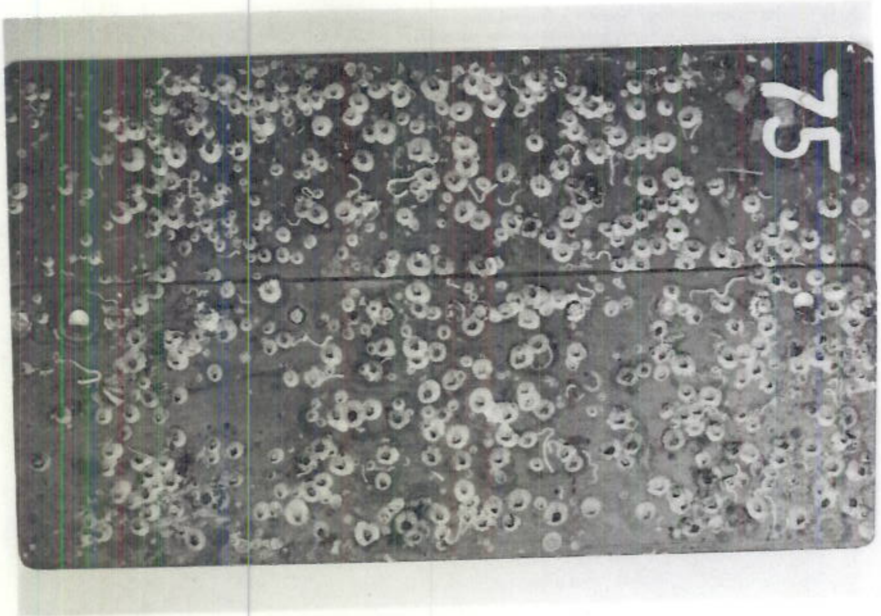

FIG. 2

PLATE 52

FIG. 1

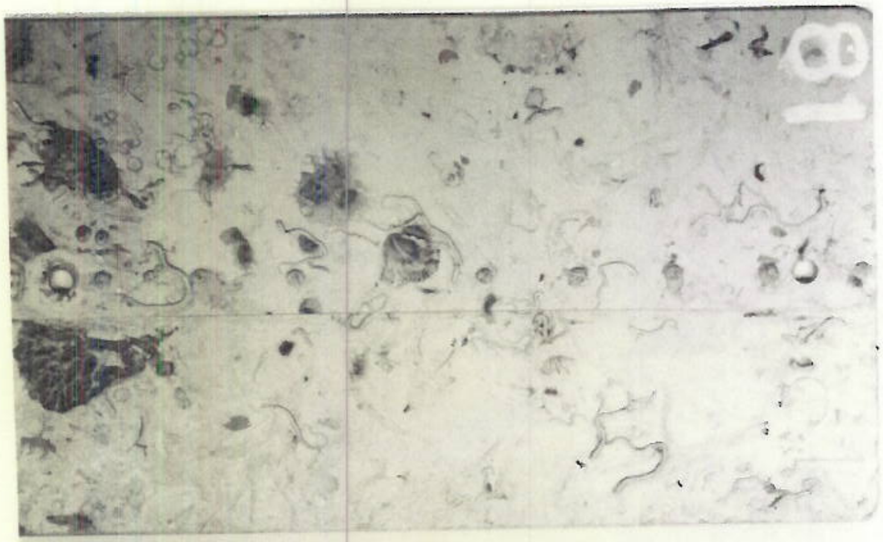

FIG. 2

PLATE 53

FIG. 1

FIG. 2

PLATE 54

FIG. 1

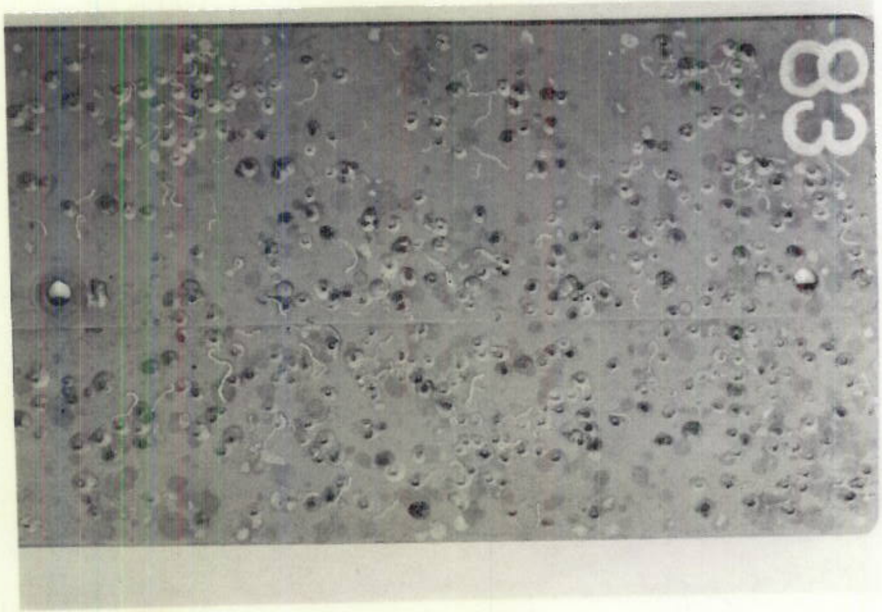

FIG. 2

PLATE 55

FIG. 1

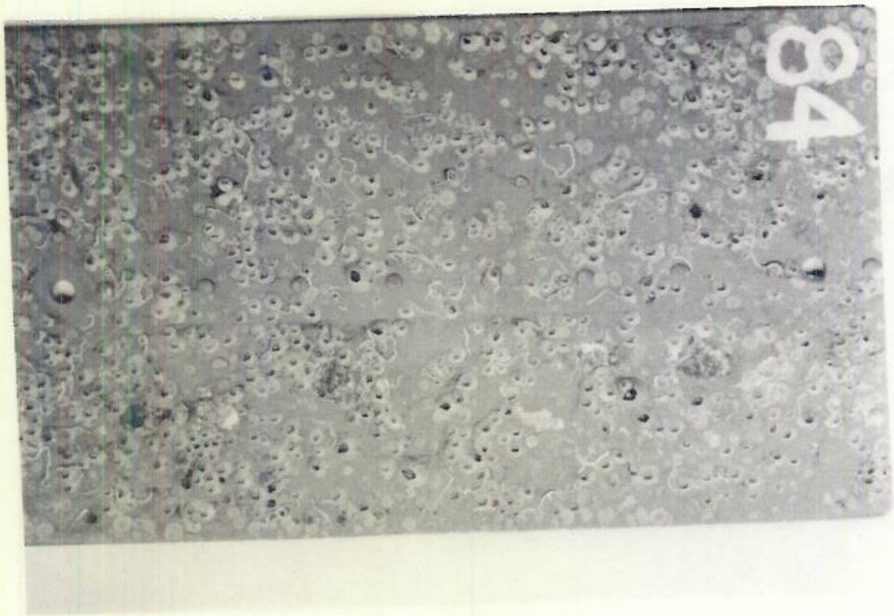

FIG. 2

PLATE 56

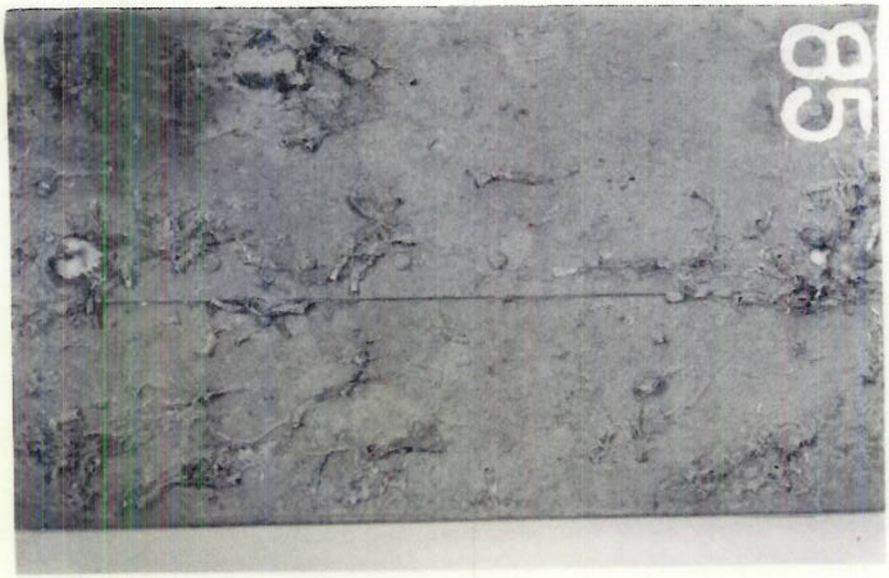

FIG. 1

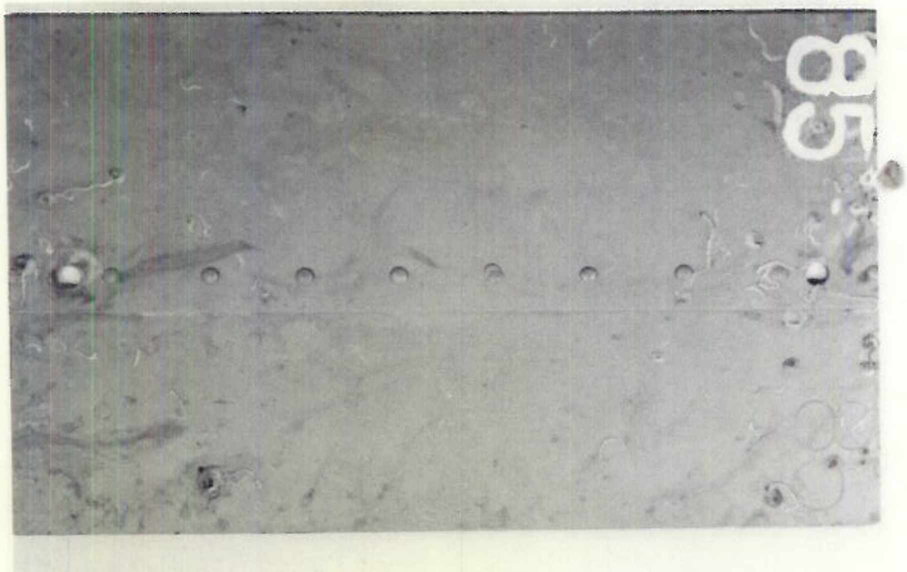

FIG. 2

PLATE 57

FIG. 1

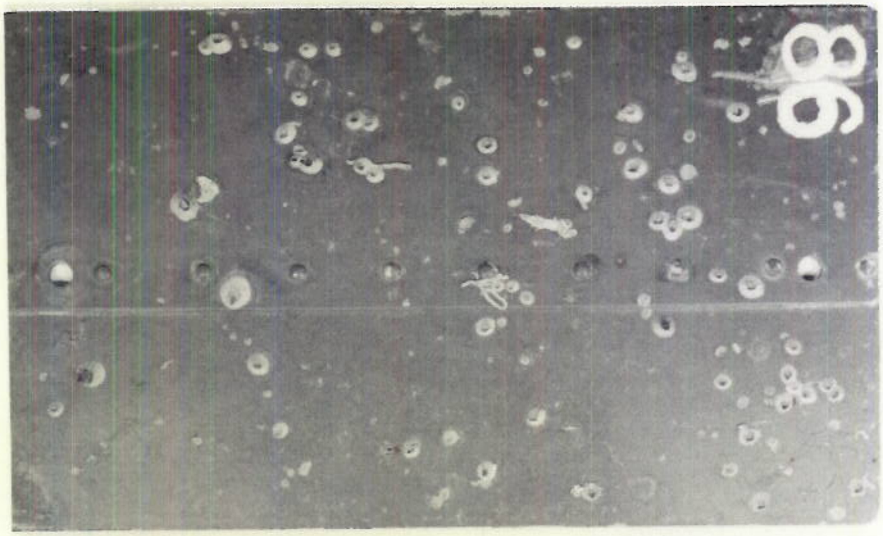

FIG. 2

PLATE 58

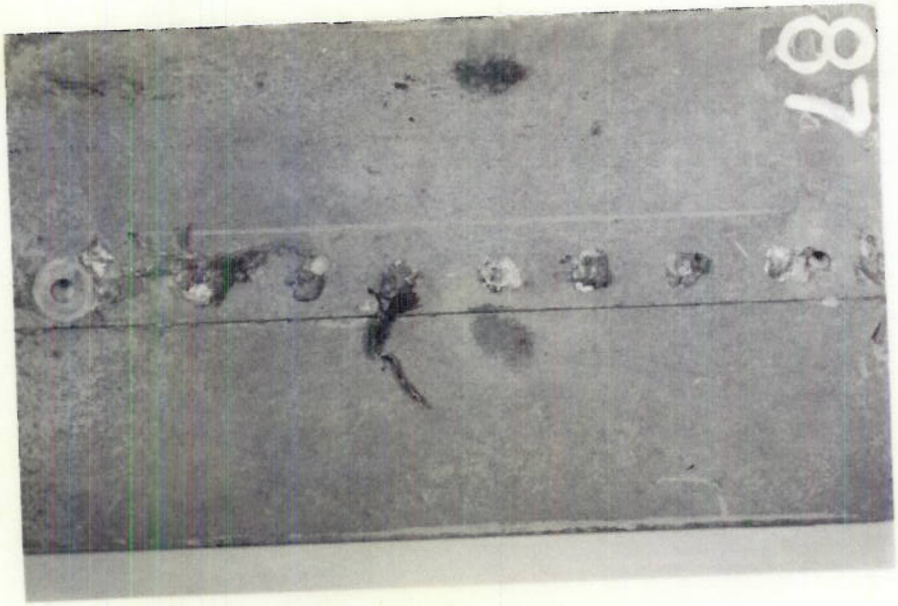

FIG. 1

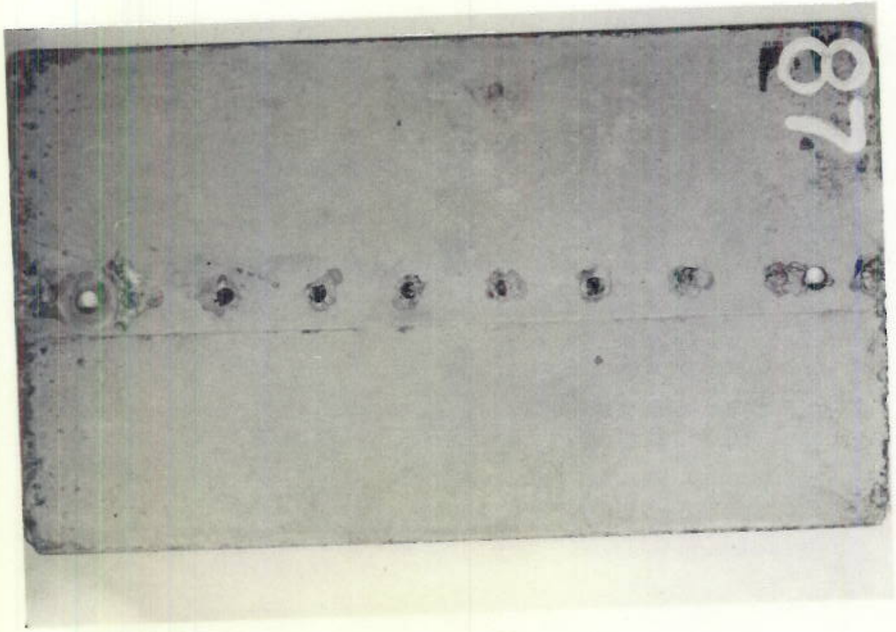

FIG. 2

PLATE 59

FIG. 1

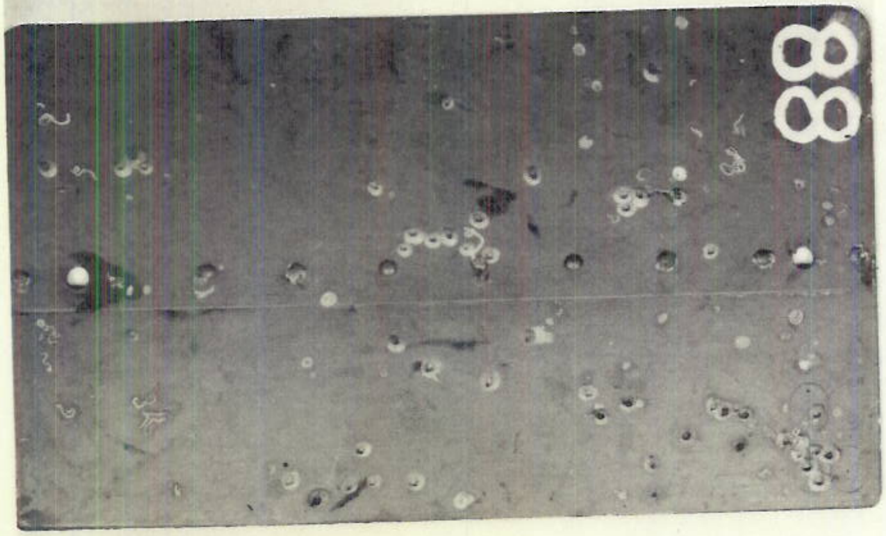

FIG. 2

PLATE 60