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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Subjecting Marine Antifouling Coating to Biofouling and Fluid Shear Forces in Natural Seawater[1]

This standard is issued under the fixed designation D 4939; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of antifouling performance and reduction of thickness of marine antifouling (AF) coatings by erosion or ablation (see Section 3) under specified conditions of hydrodynamic shear stress in seawater alternated with static exposure in seawater. An antifouling coating system of known performance is included to serve as a control in antifouling studies.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For a specific hazards statement, see Section 8.

2. Referenced Documents

2.1 *ASTM Standards:*

A 569/A 569M Specification for Steel, Carbon (0.15 Maximum Percent), Hot-Rolled, Sheet and Strip, Commercial Quality[2]

D 1186 Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base[3]

D 2200 Pictorial Surface Preparation Standards for Painting Steel Surfaces[4]

D 3623 Method for Testing Antifouling Panels in Shallow Submergence[4]

2.2 *U.S. Military Specifications:*[5]

MIL-P-24441 Primer, Epoxy (Formula 150, Formula Sheet 24441/1)

MIL-P-15931B Paint, Antifouling, Vinyl, Red (Formula 121/63)

MIL-S-22698A Steel Plate, Carbon, Structural

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *ablation*—in this test method, the removal or wearing away of the outer layers of coating caused by the combined action of hydrolysis and hydrodynamic shear stress. This action is often, but not necessarily, achieved by the combined effects of hydrolysis and hydrodynamic shear stress.

3.1.2 *hydrolysis*—softens or weakens the outer layers, permitting the hydrodynamic shear stresses gradually to remove them, continually exposing a fresh antifouling surface.

3.1.3 *hydrodynamic shear stress*—the force tangential to the surface resulting from water in contact with and flowing parallel to the surface.

4. Summary of Test Method

4.1 The antifouling coatings to be tested and a control coating are applied to steel panels and exposed in natural seawater at a site where the fouling rate is high. The exposure consists of alternate static and dynamic cycles of typically 30 days each for a total length of time to be specified (such as one or two years) or until some selected degree of fouling is reached. The static exposure is conducted in accordance with Method D 3623 except that the panels are smaller and are preformed to fit a rotating drum. The dynamic exposure consists of subjecting the test panels to a shear stress by rotating the drum underwater at some specified revolution rate; typically, that rate that gives a peripheral speed of 15 knots (7.6 m/s). See Note 1 for an example. Photographs and film thickness measurements (made in accordance with Test Methods D 1186) are taken before exposure to seawater and, along with fouling ratings, at intervals during exposure.

NOTE 1—Consider antifouling paint for a ship about 500 ft in length that cruises at about 20 knots. From Table 2, the column for 20 knots shows the hydrodynamic shear stress, τ varying from 2.01 to 1.40 lbf/ft^2 over a flat plate with approximately the same length as the ship. From Table 1, a rotating drum with a radius of 0.75 ft with a peripheral speed of 15 knots gives a τ of 1.72 lbf/ft^2. To subject the paint to about the same range of τ as on the ship, the paint can be tested on the drum with τ of 1.72 lbf/ft^2. Because τ for the plate (and ships) decreases from the leading to the trailing edge, it is considered adequate to select τ for the drum as the approximate midrange of the plate values matched to the length and cruising speed of the vessels of interest.

5. Significance and Use

5.1 Effective antifouling coatings are essential for the retention of speed and reduction of operating costs of ships. This test method is designed as a screening test to evaluate antifouling

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[1] This test method is under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.45 on Marine Coatings.

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[2] *Annual Book of ASTM Standards*, Vol 01.03.

[3] *Annual Book of ASTM Standards*, Vol 06.01.

[4] *Annual Book of ASTM Standards*, Vol 06.02.

[5] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094.

TABLE 1 Approximate Hydrodynamic Shear Stress, τ, For Rotating Drum Apparatus, lbf/ft² [A]

Drum Radius, ft	Peripheral Speed of Drum, knots					
	10	15	20	22	25	30
0.75	0.82	1.72	2.91	3.48	4.39	6.14
1.0	0.78	1.64	2.78	3.31	4.19	5.86
1.25	0.75	1.58	2.68	3.20	4.05	5.68
1.5	0.73	1.53	2.60	3.11	3.94	5.52

[A] Values calculated as follows:

$\tau = \frac{1}{2} C_f \rho v^2,$

$v = r\omega$

$R = \frac{vr}{\nu}$, Reynolds Number

$\frac{1}{\sqrt{C_f}} = -0.6 + 4.07 \log [R\sqrt{C_f}]$ (from Dorfman, *Hydrodynamic Resistance and the Heat Loss of Rotating Solids*, Oliver and Boyd, London, 1963, p. 176.

where

τ = shear stress on drum surface, lbf/ft²,
ρ = water density = 1.99 slugs,
v = peripheral speed of drum surface, knots,
C_f = shear stress (drag) coefficient,
ω = Rotational speed of drum, radions/s, and
r = drum radius, ft.

coating systems under conditions of hydrodynamic stress caused by water flow alternated with static exposure to a fouling environment. A dynamic test is necessary because of the increasing availability of AF coatings that are designed to ablate in service to expose a fresh antifouling surface. Because no ship is underway continually, a static exposure phase is included to give fouling microorganisms the opportunity to attach under static conditions. After an initial 30-day static exposure, alternated 30-day dynamic and static exposures are recommended as a standard cycle. The initial static exposure is selected to represent vessels coming out of drydock and sitting pierside while work is being completed. This gives the paint time to lose any remaining solvents, complete curing, absorb water, and, in general, stabilize to the in-water environment.

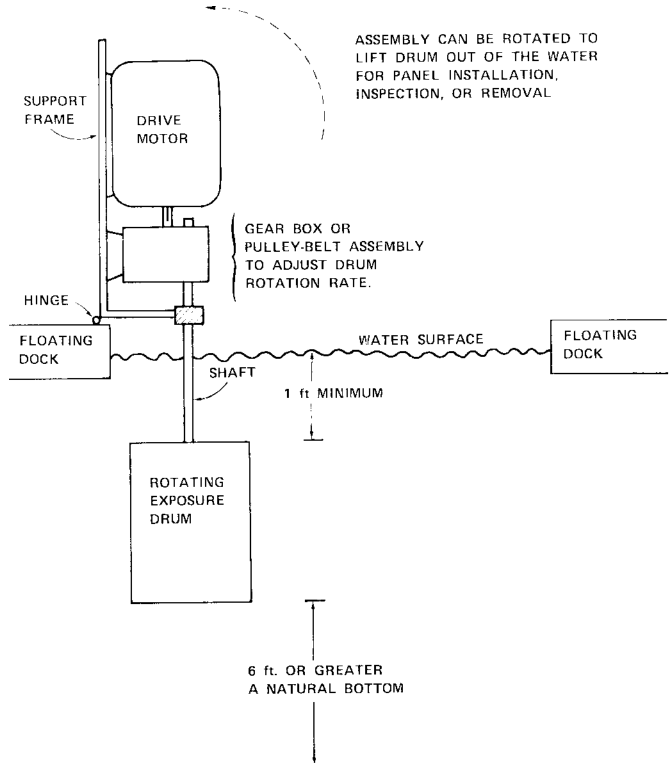
5.2 This test method is intended to provide a comparison with a control antifouling coating of known performance in protecting underwater portions of ships' hulls. This test method gives an indication of the performance and anticipated service life of antifouling coatings for use on seagoing vessels. However, the degree of correlation between this test method and service performance has not been determined.

6. Apparatus

6.1 *Rotating Drum Assembly*—The basic system consists of a rotating drum assembly as shown in Fig. 1. The drum diameter and rotational rate shall be calculated to give the desired hydrodynamic shear stress. The drum diameter shall be not less than 18 in. (460 mm).

6.2 *Panels*—The panels shall be made from medium low-carbon steel plate in accordance with Specification A 569/A 569M, ⅛ in. thick by 3 to 6 by 7 to 10 in. (3 mm thick by 80 to 150 by 180 to 250 mm) curved to fit the drum surface as shown in Fig. 2. Panel length must be selected in order to prevent gaps greater than 1⁄16 in. (1.6 mm).

6.3 *Static Exposure Rack*—The static exposure rack shall provide firm positioning of the specimen panels so that the



NOTE 1—Specific components and arrangements may vary to suit user and site requirements.
NOTE 2—1 ft = 305 mm.

FIG. 1 Rotating Drum Assembly

coated surfaces are held vertically in place in spite of the current and are electrically insulated from metallic contact with the rack or other panels. The rack shall be so positioned that the prevailing tidal currents move parallel to the panel face, and the panels are immersed to a depth of a minimum of 1 ft (0.3 m) and a maximum of 10 ft (3 m). In a rack where panels are stacked front to back, they should be spaced at least 2½ in. (64 mm) apart, with the two end positions filled with blank panels. In a rack where the panels are mounted side by side, the distance between adjacent panels should be not less than ½ in. (13 mm).

7. Materials

7.1 *Control Coating System*—The control antifouling coating system shall consist of the following system unless an alternative control coating system is specified.

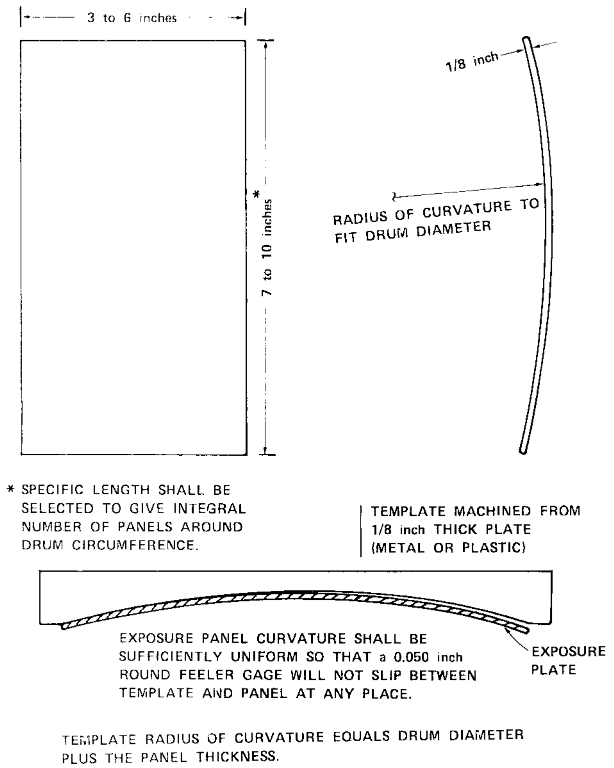
7.1.1 *Polyamide Epoxy Anticorrosive Coating*, conforming to U.S. Military Specification MIL-P-24441 (Navy Formula 150, Type I).

7.1.2 *Vinyl Antifouling Coating*, conforming to U.S. Military Specification MIL-P-15931B (Formula 121/63), B revision only.

7.2 *Test Coating System*—The antifouling coating under test may be applied to the control primer system or to any other suitable anticorrosive primer system agreed upon between the parties concerned. The application procedure is to be in accordance with the manufacturer's instructions.

8. Hazards

8.1 Antifouling paints contain toxic materials that could



NOTE 1—1 in. = 25.4 mm.

FIG. 2 Curved Exposure Panels for Rotating Drum

cause skin and eye irritation on contact and adverse physiological effects if ingested or inhaled. In the preparation of panels and the application of various types of antifouling paints the use of appropriate protective clothing and equipment is required consistent with applicable regulations, and recognized industrial and technical standards. Do not flush spills, overspray, and unused material down the drain, but disposed of as hazardous waste.

9. Procedure

9.1 Abrasive blast clean the required number of panels (six panels for each coating system being tested) to near white metal (Grade Sa 2½ of Pictorial Standard D 2200) to obtain a profile from 1 to 1.5 mils (25 to 40 µm).

9.2 On the clean, dry, uncontaminated, blast-cleaned surface apply to each standard panel one coat of epoxy polyamide primer conforming to MIL-P-24441 to give a dry film thickness of approximately 3 mils (75 µm). After about 24 h, (for temperatures above 70°F and below 90°F), apply a second coat of the primer to the panels. After a second 24-h period, apply the third coating of primer to give a total dry film thickness of approximately 9 mils (230 µm).

9.3 Apply the vinyl antifouling coating conforming to MIL-P-15931B before the final coat of epoxy paint has hardened. The epoxy should be slightly tacky when the first coat of the topcoat is applied. If the epoxy is hard (usually after 8 h) apply a tack or mist coat of 1 to 2 mils wet film thickness and allow to dry to a slightly tacky state before applying the first coat of the topcoat. Allowing a minimum of 2 h and a maximum of 24 h drying after the first coat, apply the second coat of the antifouling coating conforming to MIL-P-15931B to give a nominal dry film thickness of the antifouling paint of 4 mils (100 µm).

9.4 Before immersion permit the second coat of antifouling coating to dry a minimum of 24 h or until fully cured in accordance with the manufacturer's recommendations and a maximum of one month, the latter time allowing for shipping the panels to the immersion site. Measure dry film thickness at ten locations on the panel in accordance with Test Methods D 1186 prior to immersion at the site. To accurately locate the thickness measurement locations on the panels for repeated measurements, use a mask with two rows of five holes equally spaced over the surface.

9.5 Exposure consists of alternating static and dynamic phases at an immersion site with a high incidence of fouling (that is fouling resistance of 50 % or less determined in accordance with Method D 3623) as indicated by attachments to a dark nontoxic surface such as slate.

9.5.1 Place the panels on the stationary exposure racks, handling them only by the edges, and expose them in accordance with Method D 3623. Static exposure may be accomplished by leaving the panels attached to the drum and not rotating it. The time the panels are out of the water must be kept to a minimum. When any panels are removed from the stationary racks or the rotating drum, they are to be kept in containers of seawater except during actual rating, photography, or thickness measurement. If the time out of water exceeds 10 min, this fact should be recorded and reported.

9.5.2 Subject the test panels to dynamic exposure by mounting them on the drum and rotating it at a peripheral speed calculated from the values and formulas given in Table 1 and Tables 2 as agreed upon between the parties concerned.

9.6 Evaluate the antifouling panels for surface fouling and physical condition of the film system at the end of each exposure or as agreed upon between the parties concerned. Record the evaluation on the report form in Fig. 3.

9.6.1 *Fouling on Surface*—Rate the fouling present on that portion of the antifouling test surface that is intact at the time of inspection in accordance with Method D 3623. Ignore fouling present on the substrate or on anticorrosive undercoats. Barnacles, polychaetes, coelenterates, etc. that are immature or loosely attached should be so reported in the appropriate space on the report form (see Fig. 3). Report fouling by initial algal germination, low-form algae, and diatoms as" algal slime." Report absorbed organic and inorganic chemicals, trapped silt and detritus, and other unidentified slimes as "silt."

9.6.2 *Physical Condition*—Rate the condition of coating films in accordance with 10.2. Record qualitative descriptions of film deterioration and discoloration in the appropriate column in Fig. 3 unless otherwise specified. Indicate deterioration of anticorrosive (AC) undercoats, when evident, by the notation "AC." For example, "Peeling antifouling film (AF) from AC" or "Chipping, AC from steel." For ablative coating with fouling-free areas, measure total coating thickness in accordance with Test Methods D 1186 using the mask to locate measurement spots. If the panel surface is free of fouling, Behavior Report of Experimental Surfaces

Origin:	Place of Immersion:
Series:	Depth of Immersion:
Base:	Date Immersed:
Size:	Date Inspected:
	Inspected by:

Test Surface No.	Fouling on Surface	Physical Condition	Percent Ratings			
			FR	AF	AC	OP
	Barn: EB: Others:					
	Barn: EB : Others:					
	Barn: EB: Others:					
	Barn: EB: Others:					
	Barn: EB: Others:					
	Barn: EB: Others:					
	Barn: EB: Others:					

NOTE 1—Fouling is reported as found on the more heavily fouled surface. Solitary forms are reported numerically; colonial forms by percent surface covered. Abbreviations: algae (Al); barnacles (Barn); encrusting bryozoans (EB); hydroids (Hyd); tunicates (Tun); completely fouled (CF); coelenterates (CO); filamentous bryozoans (FB); molluscs (Mol); polychaetes (PC).

FIG. 3 Report Form

measure thickness at all ten locations given on the mask. If any locations are obstructed by fouling, note this fact and do not make measurements at that spot.

9.7 Record the start and stop dates of each of the static and dynamic exposures. Record each of the inspection dates. During the exposures, record the range of water depth, temperature, salinity, pH, and water solids content at intervals using the methods agreed upon by the parties concerned.

9.8 Document the exposure results as follows:

9.8.1 Take color photographs and coating film thickness at ten locations marked by the mask in accordance with Test Methods D 1186 prior to immersion. Repeat the film thickness measurement at the end of the first static exposure to allow for film swelling and to provide a reference for the amount of paint thickness lost during the subsequent dynamic exposures.

9.8.2 At the end of each phase, take color photographs of each set (six panels including color chart), determine coating dry (or cured) film thickness in accordance with Test Methods D 1186 prior to the first and after each succeeding dynamic-exposure phase, and determine fouling rating in accordance with Method D 3623.

10. Calculation

10.1 *Fouling Resistance (FR)*—Calculate the fouling resistance in accordance with Method D 3623 except do not normalize the results.

10.2 *Physical Change*:

10.2.1 *Antifouling Film (AF)*—Award an antifouling test surface having no physical defects a rating of 100. Subtract the percent surface affected by film defects from 100 to obtain the rating for imperfect films.

10.2.2 *Anticorrosive Film (AC)*—Obtain the rating in accordance with the procedure in 10.2.1.

10.3 *Overall Performance (OP)*—For overall performance, award the panel the lowest percent rating of the three preceding values: FR, AF, and AC.

10.4 *Paint Thickness*—Average the initial ten film thickness readings per panel made after the first static exposure; average the final thickness readings after the last exposure. Compute the average thickness loss by subtracting the average final thickness from the average initial thickness. Calculate the number of months over which the film thickness loss occurred.

11. Report

11.1 Report the following information:

11.1.1 The results of the immersion test in terms of fouling resistance and overall performance for both the material under test and the control system.

11.1.2 The initial and final film thickness for each panel, the film thickness loss, and the months over which the loss occurred.

11.1.3 The place, depth, and date of immersion; whether mounted from a dock, a floating raft, or in a man-made flow tank; the drum diameter and r/min; the date the panels were removed and inspected; the panel size; the panel identification number; and the range of the water temperature, salinity, pH, and water solids content on a monthly basis. A census of the fouling on a nontoxic surface taken each month for the period of exposure must be included in the report. Color photographs of the fouling and coating are to be taken at the end of each exposure or as specified.

12. Precision and Bias

12.1 Precision and bias cannot be determined. Only alimited number of test facilities[6] have constructed this apparatus and utilized this test procedure to date. Furthermore, the test method was developed and used only for prototype testing. This means few specimens of a kind have been tested or are likely to be tested with results suitable for analysis available in the next few years. Also, since there is no acceptable reference material suitable for determining the bias for this procedure, no statement on bias is being made.

[6] Facilities that have constructed this apparatus include Miami Marine Research Inc., 547 West Ave., Miami Beach, FL 33139 and Battelle Columbus Laboratories, Florida Marine Research Facility, 4928 Sailfish Drive, Ponce Inlet, Daytona Beach, FL 32019.