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UNDERWATER APPLIED COATINGS: A STATE-OF-THE-ART INVESTIGATION

by

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COVER PHOTOS:

TOP - Preparation for diving

BOTTOM - Standard spray gun modified for underwater use.

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<p>Eleven proprietary protective coatings of differing composition, formulated for application to damp or immersed surfaces, and a quick-setting hydraulic cement material were procured for testing to determine their applicability for underwater maintenance painting. They were applied to dry steel, to steel wetted with fresh water, and to steel immersed in fresh and salt water. Variations in test methods included surface preparation (abrasively blasted, water blasted, and wire brushed), application (hand/glove, putty knife, brush, and roller, as appropriate), and water (fresh and salt). The coated steel specimens were subsequently subjected to a pull test to establish the film properties. Most products were easily applied to dry and wetted steel, but many were applied to immersed</p> <p style="text-align: right;">(cont'd)</p>			
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steel only with great difficulty. Only the thick splash-zone products and two of the eight brushable products were relatively easily applied to immersed steel. These products all cured to form durable films. Abrasive blasting was the preferred method of surface preparation. Adhesive/cohesive properties determined in pull tests were in most cases about the same in fresh as in salt water.

Two products were also applied by a diver. The first product was easily applied by brush and cured to give a good film. The other, thicker product was more difficult to apply by hand, and the properties of the cured film were inferior to those of specimens applied in the laboratory.

PREFACE

This study was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), under Civil Works Research Work Unit 32373, "Painting of Submerged Surfaces," for which Mr. Alfred D. Beitelman was Principal Investigator. Funds for testing, compilation of the data, and preparation of this report were provided through the Electrical and Mechanical Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program, for which Mr. Robert L. Kinsell, (CEEC-EE) was the HQUSACE Technical Monitor.

Mr. Jesse A. Pfeiffer, Jr., was the REMR Coordinator of the Directorate of Research and Development, HQUSACE; Mr. Jim Crews, Mr. Bruce L. McCartney, and Dr. Tony C. Liu served as the REMR Overview Committee; Mr. William F. McCleese was the REMR Program Manager; Mr. Paul Howdysshell was the Problem Area Leader when this study was accomplished; Mr. Ashok Kumar then became the Problem Area Leader.

This work was conducted by the Naval Civil Engineering Laboratory (NCEL) for the US Army Construction Engineering Research Laboratory (USA-CERL) under the general supervision of Dr. R. Quattrone, Chief, Engineering and Materials Division (EM). The Technical Editor was Gloria J. Wienke, Information Management Office.

COL Norman C. Hintz was Commander and Director of USA-CERL when this study was accomplished; COL Carl O. Magnell then became Commander and Director. Dr. L.R. Shaffer was Technical Director of USA-CERL.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
gallons (US liquid)	3.785412	litres
inches	25.4	millimetres
mils	0.0254	millimetres
pounds (force) per square inch	6.894757	kilopascals
square inches	6.4516	square centimetres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

UNDERWATER APPLIED COATINGS:
A STATE-OF-THE-ART INVESTIGATION

PART I: INTRODUCTION

Background

1. Protective coatings formulated for application to damp and underwater steel surfaces have been available for many years (Drisko 1979). Applying these products is a slow and costly process, but their use may well be justified for underwater maintenance painting of such important exposed steel surfaces as hulls of ships, caissons, locks, and piling that could not otherwise be conveniently protected. New products reported to be technological breakthroughs have appeared on the market from time to time, while others that had received much notoriety have disappeared. Because of the many potential uses of these products, the US Army Construction Engineering Research Laboratory (USA-CERL) requested the Naval Civil Engineering Laboratory (NCEL) to conduct a state-of-the-art investigation of available underwater applied coatings and test them to determine their practicality.

Objective

2. The objective of this work was to test the properties and practicality of underwater applied coatings.

Approach

3. An extensive telephone survey was conducted to identify all the coatings formulated for application to damp or immersed surfaces that are presently marketed. Some suppliers of splash-zone compounds are relatively large firms, but the brushable products are more often marketed by small specialty companies. Twelve products of differing compositions were procured for laboratory testing. No attempt was made to procure and test all possible splash-zone compounds because they are all quite similar.

4. The products were applied to dry steel, to steel wetted with fresh water, and to steel immersed in fresh and salt water. The steel surfaces were prepared by abrasive blasting, waterblasting, and wire brushing. The products were applied with a putty knife, brush, roller, or by hand/glove. Two products were also applied by a diver using a brush and by hand/glove. The cured films were subjected to a pull test to determine adhesive/cohesive properties.



PART II: HISTORY OF UNDERWATER COATING

5. A practical system for coating structures located between tides or under water has long been sought. Any such system would be very costly, but the expense may be justified for many applications.

6. The cofferdam is an old concept that is still occasionally used for applying underwater coatings (Schultz 1976). A watertight box constructed of metal, wood, or plastic is pressed against the structure to be coated and pumped dry to expose surfaces normally immersed. The exposed surfaces are then cleaned and coated by conventional means. NCEL found that MIL-P-24441 (epoxy-polyamide) and Steel Structures Painting Council (SSPC) Paint 16 (coal tar epoxy-polyamide) can be applied in this manner and will cure under water after the cofferdam has been removed (Drisko and Brouillette 1971, Steel Structures Painting Council 1982). Use of the cofferdam is generally restricted to simple structures and shallow depths.

7. In 1962, the Shell Chemical Company provided to coating suppliers a two-component formulation for a puttylike material called "splash-zone compound" that could be applied to damp or immersed surfaces (Jorda 1963, Materials Performance 1963). Almost immediately, several suppliers began marketing products with this formulation or a slight variation of it. Splash-zone compounds are still marketed today. They all consist of differently colored, viscous epoxy and polyamide components that are mixed in equal volume by a power stirrer until a uniform color results. Once mixed, the material can be picked up with wet hands and pressed against a clean underwater surface to a thickness of 125 to 250 mils.* The mixed product is slightly water-soluble and can be slowly eroded with wet hands to produce a smooth coating. The applied product cures overnight at temperatures above 60° F. At temperatures below 60° F, the curing rate is too slow for practical use. Sometimes the components are preheated, mixed, and allowed to react for an hour or more before application at temperatures below 60° F to give the curing a "kick," but

* A table of factors for converting non-SI units of measurement used in this report to SI (metric) units is presented on page 3.

this procedure is only slightly effective. Abrasive blasting results in the best adhesion (Drisko 1979), but other cleaning methods, such as a needle gun with 0.08-in.-diameter needles may be satisfactory.

Fiberglass, burlap, or canvas applicators have been used to apply the product, but manual application (the "patty-cake" method) is still the most widely used technique.

8. Because of the limitations of splash-zone compounds, several thinner coatings have been developed for application to damp or immersed surfaces by brush or roller (Drisko 1968, 1975, and 1979). They are mostly epoxy formulations, but coal tar epoxy and polyester products have also been marketed. Although most of them are solvent-free, some may contain small amounts of organic solvent and are at least slightly water-soluble. Polyester products have been found to be rather easily applied under water, but they cure to a relatively soft film.

9. NCEL developed an epoxy formulation for underwater application that has been sold commercially (Drisko 1979). The original formulation is shown in Table 1. Some of the specified raw materials are not currently available, so substitutions must be made.

10. The NCEL product was not easily applied under water without adding 4 percent organotin wetting agent, corresponding to about 1 percent tin metal. The wetting agent imparted fouling resistance. If tributyl tin oxide was added until the total tin concentration of the mixed product was 6 percent, the resulting cured film completely controlled fouling for 3 years (Drisko 1977), about the same level of protection as a conventional cuprous oxide antifouling agent (e.g., MIL-P-15931). Organotin antifouling paints, however, are not permitted on the hulls of Navy ships because of possible health or environmental effects. The NCEL product can be applied using a stiff brush, a medium-napped roller, or a special plastic applicator (Drisko 1979). The Naval Coastal Systems Center developed a delivery system using compressed air to transfer the paint to the brush or roller (Drisko 1979).

PART III: EXPERIMENTAL INFORMATION

Experimental Design

11. An experimental design was prepared for laboratory testing of (a) the ease of application of 14 products for use under water and (b) the type of protective film produced. The variables in the design included three types of surface preparation (abrasive blasting, waterblasting, and wire brushing), variable types of application (e.g., brush, roller, putty knife, and hand/glove), fresh and salt water, and 12 types of products. The ease of application, resistance to sagging, and adhesion/cohesion properties were measured.

Products Tested

12. Three splash-zone compounds, two other thick polymeric materials, eight brushable products, and one hydraulic cement were evaluated. Product 1 is a typical two-component splash-zone compound with differently colored components. Product 2 is another splash-zone compound, slightly stiffer than Product 1. Product 3 is a splash-zone compound similar to Product 1. Product 4 is a fast-setting epoxy-polyamide putty designed to plug or seal concrete, metal, or wood structures. It comes in a stick with the two components separated. The stick material is kneaded to combine the reactants and start the curing reaction. It must be rapidly mixed and applied because of the fast set time. (Wash hands immediately after mixing.) Product 5 is a three-component polyester brushable formulation with separate ester, catalyst, and pigment components. Product 6 is based on the original NCEL formulation but is much thinner. Products 7 and 8 are differently pigmented brushable materials from the same supplier. Product 9 is a brushable epoxy formulation. Product 10 is also a brushable epoxy formulation. Product 11 is a thick epoxy product formulated for application by spatula. Products 12 and 13 are the same basic epoxy formulation with different pigment variations. Product 14 is a quick-setting hydraulic cement material that has been used to repair concrete swimming pools. It was tested in a cursory manner to determine

its feasibility for coating steel. The alkalinity in concrete coatings tends to protect steel from corrosion.

Content Analysis

13. Quick analyses were run to show the comparative solids and pigment contents of each of the organic materials tested. Weighed samples were heated at 221° F for 2 hours and reweighed after cooling to determine the solids content. They were then heated at 810° F for 2 hours and reweighed after cooling to determine the pigment content. Table 2 shows results of these analyses.

Surface Preparation

14. A private contractor waterblasted the steel panels. The surface variations were as follows: low profile sandblast, waterblast at 20,000 psi, waterblast at 15,000 psi, waterblast at 15,000 psi with injection of 30 mesh sand, and wire brushing by hand to achieve an SSPC SP-2 (Hand Tool Cleaning) surface. Waterblasting of uniformly corroded panels yielded information that was quite comparable to that of Frenzel (1983). At 15,000 psi, the black iron oxide corrosion products could be only slowly removed; at 20,000 psi, the removal rate was much faster; with injected sand at 15,000 psi, the cleaning was even faster. New zero-thrust waterblast lances do not push the diver away from the work, as occurs with underwater abrasive blasting.

Applying the Coatings

15. As much as possible, all the products were applied at the same time to minimize variations in conditions. The supplier's recommended application method was always used first, but alternative methods such as brush, roller, putty knife, and hand/glove were also investigated. Samples of each coating were applied to dry sandblasted steel and to sandblasted steel that had been dipped in fresh water and removed in order to compare both the ease of application and the film properties with those

of the same materials applied under water. Laboratory application in shallow tanks was designed to provide maximum ease of application and similar test conditions for all products. All applications were made according to the manufacturer's directions with no other special precautions taken. All specimens were coated while horizontal, but one panel with each product was then stood vertically to test for resistance to sagging.

Product 1

16. The two components of Product 1 were dry-mixed on a glass plate with a putty knife until a uniform color was achieved. Manual mixing required some effort. The mixed product was applied dry to the dry steel surface by spatula with no difficulty to obtain an irregular, scalloped surface. The other applications were made by picking up balls of the mixed product with wet hands, pressing the product against the steel, and smoothing the product out, forcing water away from the steel. The water became clouded by the emulsified material. Application was not difficult in either fresh or salt water. The product cured overnight to form a barrier about 125 mils thick.

Product 2

17. The epoxy base was hand-mixed dry with the polyamide converter on a plate with a putty knife until a uniform color resulted. It was somewhat harder to mix than Product 1, but mixing only required additional time. It was applied with the same methods and ease as Product 1 on all surfaces. It cured overnight to form a barrier about 125 mils thick.

Product 3

18. Product 3 was rather easily mixed and was applied with the same methods and ease as Product 1. It cured overnight to a hardened mass about 125 to 188 mils thick.

Product 4

19. A portion of the Product 4 stick was broken off and kneaded to mix the components and initiate the reaction. It was applied at once with the palm of the hand to the steel. It was readily applied to dry, wetted, and immersed surfaces. It set up so fast that it was difficult to apply large portions or to smooth it by rubbing with wet hands. It cured within an hour to form a barrier about 125 to 188 mils thick.

Product 5

20. The three components of Product 5 were hand-mixed in the recommended weight ratios with no problem. The mixed product was easily applied to dry or wetted steel, but could only be applied with difficulty under water. Also, it did not level well, so that it was difficult to obtain a smooth, continuous film. No method of application could successfully apply the material. It cured overnight to a thickness of about 30 mils.

Product 6

21. The two components of Product 6 were mixed in the recommended 4:1 volume ratio. The mixture was stirred in a beaker with a putty knife until uniform. It was easily brushed onto the dry and wetted steel surfaces. It was difficult to apply a continuous film under either fresh or salt water, as some areas would not stay coated. Brushing out to coat exposed areas of steel would result in other areas being exposed. Roller application was no better. The product cured overnight to a thickness of about 20 to 30 mils.

Product 7

22. The Product 7 epoxy base was combined with an equal volume of the unpigmented converter and hand-mixed until uniform. It was easily brushed onto the dry and wetted steel surfaces, but was more difficult to apply under water. The coating eroded rapidly to cloud the water, and it was difficult to cover all areas, especially in salt water. In salt water, the product had a greater tendency to recede and expose the underlying steel. It seemed to be best applied under both fresh and salt water by rolling on a thin film to coat the entire surface and then applying a heavy coat by brush. It cured overnight to dry film thicknesses of about 15 mils when applied to dry or wetted surfaces, 20 mils when applied under fresh water, and 20 to 30 mils when applied under salt water.

Product 8

23. Application of Product 8 was generally similar to that of Product 7, except there was no coating erosion. It cured overnight to dry film thicknesses of about 15 to 20 mils on the dry and wetted surfaces and about 25 to 35 mils on submerged surfaces.

Product 9

24. The Product 9 epoxy resin was thoroughly hand-mixed with its hardener in the recommended 5:1 weight ratio. It was not easily applied by brush or roller in either fresh or salt water. Small pinpoint areas would recede from the applied coat and defy brushing out. Rolling a thin film first and then brushing did not improve the coverage. Except for the receded areas, the paint looked acceptable. It cured overnight to provide a barrier about 15 to 20 mils thick on the dry and wetted specimens and 10 to 20 mils thick on submerged specimens.

Product 10

25. Equal volumes of Parts A and B of Product 10 were hand-mixed for several minutes before application. It was necessary to liquify Part B by slightly heating its container in warm water before mixing. The mixed product could not be applied under water by brush or roller to form a continuous film without small areas receding to expose the steel. It was the only product that showed a slight tendency to sag. It did not cure completely overnight but remained soft. It remained tacky for 2 days. The dry film thickness on all applications ranged between 15 and 20 mils. When applied under water, it yellowed slightly.

Product 11

26. Both components of Product 11 were heated slightly in warm water to liquify them before mixing. The mixed product was applied with considerable difficulty with a putty knife. The material had to be reapplied under water because it receded to expose bare steel. Use of a brush, roller, or hand/glove proved to be impractical. The applied coatings cured overnight to a scalloped, irregular barrier about 125 to 188 mils thick.

Products 12 and 13

27. The clear hardeners of Products 12 and 13 were easily hand-mixed with the pigmented components in the volume ratio furnished by the supplier. They were easily applied by brush to the steel panels in both fresh and salt water. Product 13 was slightly easier to apply. Application could also be made by roller, but complete coverage of all areas seemed easier to accomplish by brush. The coating surface on all the panels cured to touch in 6 hours and cured completely overnight. The

resulting dry film thicknesses were about 20 to 30 mils on the dry and wetted specimens and 30 to 40 mils on the submerged specimens. The surfaces of the coatings applied under fresh water (especially Product 13) were coarser than the coating surfaces applied under salt water. After an hour, the unused paint remaining in the can had become quite hot from the exothermic reaction. The supplier indicates that the mixed product has a pot life of about 20 to 30 minutes. In field applications, it is pre-heated and mixed with special equipment immediately prior to underwater application to give dry film thicknesses of 12 to 24 mils.

Product 14

28. The Product 14 powder was quickly mixed with water and applied with the palm of the hand to a sandblasted steel panel under water. The surface of the patch eroded rather rapidly until the rapid set occurred (1 hour). The hardened mass was about 125 mils thick.

Underwater Application

29. Two of the materials more easily applied in the laboratory (Products 4 and 13) were subsequently applied by a diver in the NCEL diving tank to obtain data on actual diver application. Previous NCEL experience using Navy divers in the diving tank showed that application by divers is much more difficult than application in shallow tanks in the laboratory.

30. Product 4 (a putty-like material) and Product 13 (a brushable epoxy) were applied under salt water at 74° F. The splash-zone compounds were not tested, because there is extensive field experience with these materials (Drisko 1979). Product 13 was easily brushed on by a diver wearing rubber gloves (Figure 1). It cured overnight to a dry film thickness of about 25 to 30 mils. Product 4 was applied with a little more difficulty (Figure 2). This may have been caused by difficulty in thoroughly mixing a whole stick of the putty at one time. It was hard to mix completely the two separate components in large quantities by slowly kneading the product within the pot life of the mixture. The applied product cured rapidly to a thickness of about 125 to 188 mils. Some of Product 13 got onto the surface of Product 4 from the driver's gloves, as evidenced by black streaking.



Figure 1. Diver applying Product 13 to sandblasted steel panel



Figure 2. Diver applying Product 4 to sandblasted steel panel

31. Products 1 through 4 were also applied under water to concrete. Application to clean concrete surfaces was as good as, if not better than, application to clean, abrasively blasted steel. Indeed, the naturally textured finish of concrete seemed to permit better application and bonding. The products seemed capable of plugging leaks and making a variety of other repairs to immersed concrete.

Pull Testing

32. The steel specimens that were coated while immersed, were removed from the water after curing overnight and allowed to dry for 8 hours. Dumbbell-shaped steel probes with 0.16-sq-in. ends were then bonded onto the coated surfaces with Hysol EA 9309 adhesive and allowed to set overnight. The following day, they were pulled to failure in an Instron Model 1122 testing machine with a load cell of 1,100 lb, a pulling rate of 0.2 in./min, and a full scale of 440 lb. Either the breaking force or the peak force was recorded, whichever was higher. With some specimens, there was no sharp break, but a gradual pulling apart. In these cases, the peak force was measured. With a sharp break, the peak and break values were virtually the same. The mechanism of failure was noted as: (A), failure of the adhesive bond to the coating; (C), cohesive failure bond of the coating itself; or (S), pulling of the coating from the steel, to denote the relative adhesive and cohesive properties of the different products tested. With the NCEL epoxy, the adhesive usually failed near the surface at fairly low values for most of the specimens. Thus, the test was repeated on these specimens after wiping the amine sweat off the surface with solvent immediately before applying the adhesive. The pull test was also repeated on Product 5 after solvent wiping, because this product also failed near the coating surface and it was believed that styrene migration to the surface might have affected the adhesion of the probes. The test results are recorded in Table 3. For Army use, it may be possible to specify a coating based on the pull strength rather than on product name.

33. Product 4 was relatively soft and poorly bonded (could be peeled away from the steel with a knife). This may have been caused by the large amount of product mixed at one time or contamination with Product 13.

34. The two diver-applied materials were also pull-tested. The test results are given in Table 4.

PART IV: DISCUSSION OF EXPERIMENTAL RESULTS

35. The splash-zone compounds (Products 1 through 3) were rather easily, although slowly, applied to steel immersed in fresh and salt water. In the pull test, these applications generally suffered cohesive failures. Thus, their bonding strengths were probably adequate for most needs. The cohesive strength of Product 3 was much less in fresh than in salt water.

36. Product 4 was a special material that is probably more suitable for making structural repairs (the intended use) than as a coating. When applied in relatively small amounts, it can be used for a variety of repairs.

37. Although Products 5 and 6 had been quite easily applied several years earlier (Drisko 1979), their current application difficulties are attributed to the fact that the supplier's change in formulation adversely affected the products. For Product 6, the change in formulation was obvious from the greatly reduced viscosity.

38. Although most of the brushable products could be easily applied to dry or wetted steel, only Products 12 and 13 (differently pigmented variations from the same supplier) could be readily applied under water. Product 13 was also easily applied by a diver. Although the pull test results were slightly lower for the diver-applied material, they were adequate. The supplier indicated that the high chlorine content in fresh water may adversely affect application properties.

39. Products 7 and 8, differently pigmented variations from the same supplier, had much less bonding strength in salt than in fresh water.

40. The brushable products were all found to be at least as easily applied by brush as roller, and brushing seemed the more convenient method.

41. Wire-brushed specimens almost always gave lower pull strengths than did corresponding sandblasted specimens. The failure mechanism for Products 12 and 13 was different on differently prepared surfaces: cohesive on the sandblasted steel and adhesive on the wire-brushed

steel. Results with waterblasted panels were variable but usually produced lower values than with the sandblasted panels.

42. Most of the experiments were conducted in the laboratory where it was much easier to control conditions. It is obvious that diver surface preparation and diver application are accomplished with much more difficulty. Thus, any product that was not easily applied in the laboratory could not be expected to be easily applied by divers. Only splash-zone Products 1 and 2, which have been used extensively in the field, and brushable Products 12 and 13, relatively new products, seem practical for general field use. Products 12 and 13 sell for about \$85 per gallon.

PART V: CONCLUSIONS

43. Commercially sold products for coating immersed steel surfaces are either the putty-like splash-zone compounds developed in the 1960s or the thinner, brushable products developed in recent years.

44. Commercially available splash-zone compounds are generally applied satisfactorily to give thick (e.g., 188 mils) protective coatings, but are slow and expensive to apply. Also, they cannot be used in water below 60° F.

45. Commercially available products for application by brush under water are usually much more difficult to apply than indicated in the suppliers' advertising. Only Products 12 and 13 (from the same supplier) were easily applied both by brush in the laboratory and by a diver. They formed tightly adhering protective films.

46. Abrasive blasting is the recommended method of surface preparation for steel to be coated under water because of the resulting pull strengths.

47. It may be possible to select a satisfactory product by specifying a minimum pull strength rather than naming a proprietary product. Based on these tests, adhesion values (to sandblasted steel in salt water) of 40 kg/cm² for a brushable product and 20 kg/cm² for a splash-zone compound are recommended.

PART VI: RECOMMENDATIONS

48. It is recommended that Products 12 and 13 be considered for under water coating of steel, where special requirements arise. Products 1 and 2 may also perform satisfactorily in cases where Products 12 and 13 may not be appropriate.

49. It is recommended that divers conduct field work on Products 12 and 13 and other promising products that may be developed. This work would include determining minimum surface cleaning requirements, cleaning rates, optimum application methods, and application rates. This work is necessary before recommendations for general use of these products can be made and before detailed procedures can be established. It may also be necessary to establish a procurement document based upon performance.

50. Reasonable caution should be used both in the surface preparation and application of underwater coatings. While most of the coatings contain little, if any, solvents, they do contain epoxy resins and curing agents which are potential irritants to the skin and respiratory system. Manufacturer's directions and recommendations for occupational health protection and environmental quality should be carefully followed. Material safety data sheets should be obtained from the manufacturers. In some instances, it may be necessary to obtain job approval from a local governing body such as a state Environmental Protection Agency or Department of Ecology. In cases where the effects of chemical substances on occupational health and environmental quality are unknown, the chemicals should be treated as potentially hazardous or toxic material.

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Table 1
NCEL Epoxy Formulation

<u>Epoxy Portion</u>	
<u>Component</u>	<u>Parts by Weight</u>
Epon 828 ^a	42
Permox 143 ^b	38
Blown Fish Oil ^c	17

<u>Adduct Converter Portion</u>	
<u>Component</u>	<u>Parts by Weight</u>
Epicure 8701 ^d	11.6
Epicure 874 ^d	1.9
Epon 828 ^a	2.5

<u>Wetting Agent</u>	
<u>Component</u>	<u>Parts by Weight</u>
Reaction product of tributyltin oxide and the free fatty acids of linseed oil	4.5

^aTrade name of Shell Chemical Company epoxy resin.

^bTrade name of Eagle-Pitcher Industries, Inc. lead silico chromate pigment.

^cPacific Vegetable Company Z-7-1/2.

^dTrade name of Celanese Chemical Company amine curing agent.

Table 2
Analysis of Organic Products

<u>Product Identification</u>	<u>Percent Solids</u>	<u>Percent Pigment</u>
Product 1 Epoxy	99	60
Product 1 Catalyst	99	48
Product 2 Epoxy	99	53
Product 2 Catalyst	98	54
Product 3 Epoxy	100	64
Product 3 Catalyst	99	53
Product 4 Putty	98	58
Product 5 Polyester Component	80	6 ^a
Product 6 Epoxy	96	32
Product 6 Clear Catalyst	73	0
Product 7 Epoxy	99	3
Product 7 Catalyst	88	39
Product 8 Epoxy	99	5
Product 8 Catalyst	88	40
Product 9 Epoxy	92	58
Product 9 Catalyst	46	0
Product 10 Epoxy	99	52
Product 10 Catalyst	98	57
Product 11 Epoxy	90	55
Product 11 Catalyst	98	60
Product 12 Epoxy	99	48
Product 12 Catalyst	79	4
Product 13 Epoxy	99	47
Product 13 Catalyst	79	4

^aPigment packaged separately.

Table 3
Pull Strengths and Mechanisms of Failure of
Coated Steel Panels

Surface Treatment ^b	Pull Strength (kg/cm ²) and Failure Mechanism ^a		
	Product 1	Product 2	Product 4
Dry	83 (A); 88 (A)	70 (A); 40 (A)	31 (C); 45 (C)
Wetted	36 (A); 28 (A)	107 (C); 119 (C)	24 (C); 51 (C)
FW SBlast	51 (C); 10 (C)	12 (C); 6 (C)	15 (C); 12 (C)
FW WBlast 15A	63 (C); 32 (C)	15 (A); 19 (C)	14 (C); 15 (C)
FW WBlast 20	18 (C); 46 (C)	63 (A); 36 (A)	10 (C); 19 (C)
FW WBlast 15	16 (C); 13 (C)	13 (C); 31 (C)	14 (C); 13 (C)
FW WBrush	22 (C); 14 (C)	29 (C); 46 (C)	36 (C); 19 (C)
SW SBlast	25 (C); 25 (C)	19 (A); 36 (A)	19 (C); 22 (C)
SW WBrush	10 (C); 14 (C)	6 (C); 37 (C)	2 (C); 2 (C)

Surface Treatment	Product 5		Product 7
	Unwiped	Solvent Wiped	
Dry	37 (C) ^c ; 80 (C)	14 (A)	42 (C); 49 (C)
Wetted	27 (C); 26 (C)	20 (A)	49 (S); 66 (S)
FW SBlast	9 (C); 20 (C)	16 (C)	56 (S); 35 (S)
FW WBlast 15A	4 (C); 16 (C)	6 (C)	27 (S)
FW WBlast 20	5 (C); 7 (C)	--	29 (A)
FW WBlast 15	5 (C); 6 (C)	--	11 (S)
FW WBrush	3 (C); 4 (C)	3 (C)	3 (S); 3 (S)
SW SBlast	8 (C); 6 (C)	24 (C)	2 (S); 2 (S) ^d
SW WBrush	4 (C); 12 (C)	13 (S)	1 (S); 1 (S) ^d

(Continued)

^aProducts are grouped by similar results rather than listed numerically.

^bFW SBlast = fresh water, sandblasted;

FW WBlast 15A = fresh water, waterblasted at 15,000 psi with injection of 30 mesh sand;

FW WBlast 20 = fresh water, waterblasted at 20,000 psi;

FW WBlast 15 = fresh water, waterblasted at 15,000 psi;

FW WBrush = fresh water, wire brushed;

SW SBlast = salt water, sand blasted;

SW WBrush = salt water, wire brushed.

^cLoss of outer surface of polyester coating.

^dProduct 7 coatings applied under seawater peeled from steel in sheet by pull of probe; all coatings applied under fresh water, except on sandblasted panels, showed tendency to delaminate to a much lesser extent.

Table 3 (Concluded)

Surface Treatment	Product 6		Product 8
	Unwiped	Solvent Wiped	
Dry	43 (C); 77 (C)	114 (C)	69 (C); 78 (C)
Wetted	55 (C); 42 (C)	100 (S)	32 (S); 44 (S)
FW SBlast	19 (A); 23 (A)	22 (S); 30 (S)	52 (A); 94 (C)
FW WBlast 15A	6 (S); 5 (S)	--	19 (C)
FW WBlast 20	7 (A); 7 (A)	11 (S)	15 (A)
FW WBlast 15	6 (A); 10 (A)	11 (A)	36 (S)
FW WBrush	10 (A); 12 (C)	17 (S); 12 (S)	17 (C); 10 (A)
SW SBlast	8 (A); 14 (A)	19 (A); 17 (S)	8 (S); 6 (S) ^e
SW WBrush	6 (A); 15 (A)	19 (A)	1 (S) ^c

Surface Treatment	Product 9	Product 10 ^f	Product 11
Dry	38 (A); 66 (A)	25 (C)	105 (C)
Wetted	36 (A); 41 (A)	7 (C)	53 (C); 100 (C)
FW SBlast	51 (S); 33 (A)	3 (C); 20 (C)	29 (C); 29 (C)
FW WBlast 15A	35 (S)	3 (C)	15 (S)
FW WBlast 20	10 (A)	2 (S)	8 (S)
FW WBlast 15	10 (S)	1 (S)	30 (S)
FW WBrush	15 (S)	3 (S)	10 (S)
SW SBlast	35 (S); 53 (S)	7 (S); 1 (S)	25 (C); 42 (C)
SW WBrush	8 (S)	12 (S)	18

Surface Treatment	Product 12 ^g	Product 13 ^g	Product 3
Dry	55 (S); 38 (S)	109 (S); 111 (S)	35 (C); 65 (C)
Wetted	42 (S); 45 (S)	88 (S); 60 (S)	35 (C); 61 (C)
FW SBlast	52 (C); 55 (C)	63 (C); 33 (C)	4 (C); 6 (C)
FW WBrush	17 (S); 22 (S)	27 (S); 30 (S)	6 (C); 4 (C)
SW SBlast	56 (C); 95 (C)	73 (C); 127 (C)	24 (C); 19 (C)
SW WBrush	15 (S); 20 (S)	30 (S); 31 (S)	23 (C); 12 (C)

Surface Treatment	Product 14
Dry	1 (C); 1 (C)

^eProduct 8 coatings applied under seawater peeled from steel in sheet by pull of probe; some of the nonsandblasted coatings applied under fresh water showed a slight tendency to peel similarly.

^fProduct 10 was tacky for two days.

^gThe cohesive failure of Products 12 and 13 always occurred near the surface of the coating.

Table 4
Pull Strength of Materials Applied by Diver
to Sandblasted Steel

<u>Product</u>	<u>Pull strength</u> <u>(kg/cm²)</u>	<u>Failure</u> <u>Mechanism</u>
4	11	C
	6	C
	15	C
13	65	S
	47	C
	31	A

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UNDERWATER APPLIED COATINGS: A STATE-OF-THE-ART INVESTIGATION



	KEY	
	<u>Product Number</u>	<u>Product</u>
O'Brien Corporation South San Francisco, CA 94080	1	Napco 682 Splash-zone Compound
Koppers Vernon, CA 90040	2	Koppers A-788 Splash-zone Compound
Advent Laboratories, Inc. Orange, CA 92667	3	Epomarine #3534
Polymeric Systems, Incorporated Phoenixville, PA 19460	4	Repairit Quick (A single stick form of Kneadtite II)
Advanced Coatings and Chemicals Temple City, CA 91780	5	Advanced Polyester
Advanced Coatings and Chemicals Temple City, CA 91780	6	CEL Epoxy
Sika Corporation Lynhurst, NJ 07071	7	Sikagard 61 (Sikagard 644 Red)
Sika Corporation Lynhurst, NJ 07071	8	Sikagard 61 (Sikagard 643 Gray)
Alocit Products Warfield Company, Incorporated Broomall, PA 19008	9	Alocit Aquacoat 28.15
American Chemical Corporation Menlo Park, CA 94025	10	Aquatapoxy Paint
American Chemical Corporation Menlo Park, CA 94025	11	Aquatapoxy Gel
Underwater Technology Corporation (America) Inc. Houston, TX 77034	12	Hycote 151 Red
Underwater Technology Corporation (America) Inc. Houston, TX 77034	13	Hycote 151 Black
Thoro Systems Products Miami, FL 33136	14	Waterplug